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**THE DEVELOPMENT OF THE TERRESTRIAL
BROADCASTING NETWORKS OF THE
UNITED KINGDOM IN THE TWENTIETH CENTURY**

**A Thesis Offered for the Degree of
Doctor of Philosophy**

Department of Information and Communication Technologies

Open University

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Abstract:

The Development of the Terrestrial Broadcasting Networks of the United Kingdom in The Twentieth Century

This thesis describes an investigation into the evolution of terrestrial broadcasting - a vital new medium that has had an enormous social impact. The approach has been to concentrate upon the research and development needed to plan the intricate radio and television transmitter networks. These processes required national and international agreement on the use of the radio frequency spectrum, and the specification of many hundreds of transmitting stations. They provided the link between the broadcasters and the public, and this work presents a unique illustration of a project which dealt with many novel technical problems whilst accommodating the demands of all those concerned with the exploitation of the medium.

The UK became prominent in the field of broadcasting technology, particularly in areas concerned with propagation and service planning. The geographical position of this country between large land and sea masses, the nature of its terrain, meteorology and its population distribution, presented a wide range of distinctive problems. Research in the UK provided valuable evidence for the subsequent planning of services throughout the world, although during the rapid development of broadcasting it was impossible to examine fully all the experimental results which were produced. With resources not previously available, the author – engaged on planning work since the middle of the century - has researched evidence much of which was archived *many years ago*. *It is not simply a work of historical interest, because new information concerning radio propagation has emerged. Its timing is also appropriate, because the beginning of the twenty-first century is witnessing revolutionary changes in broadcasting.*

Key words:- Broadcasting, Television, Radio, Propagation, Meteorology, Research

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Abbreviations

AGARD	Advisory Group for Aerospace Research and Development
a.g.l.	Above ground level
AM	Amplitude modulation
BBC	British Broadcasting Corporation (from 1923 – 1926 “Company”)
BREMA	British Radio and Electrical Manufacturers’ Association
BSB	British Satellite Broadcasting
BSC	Broadcasting Standards’ Council
cci	Co-channel interference
CCIR	International Radio Consultative Committee
CCTV	Closed circuit television
COST	European Cooperation in the Field of Scientific and Technical Research
cw	Continuous wave
DBS	Direct Broadcasting Satellite
dB μ V/m	Decibels relative to 1 μ Volt/metre (field strength)
DSIR	Directorate of Scientific and Industrial Research
DTI	Department of Trade and Industry
DTT	Digital Terrestrial Television
EBU	European Broadcasting Union
EMI	Electrical and Musical Industries
ERP	Effective radiated power
E _s	Sporadic E
FM	Frequency modulation
GPO	General Post Office
HDTV	High-definition Television

HF	High frequency 300 kHz – 30 MHz
HRP	Horizontal radiation pattern
IBA	Independent Broadcasting Authority
IBU	International Broadcasting Union
IEE	Institution of Electrical Engineers
IFRB	International Frequency Registration Board
ITA	Independent Television Authority
ITC	Independent Television Commission
ITS	Institute for Telecommunications Sciences
ITU	International Telecommunication Union
IWP	International Working Party (CCIR)
LCD	Liquid crystal display
LDR	Long-distance reception/recording
LF	Low frequency 3.0 – 30 kHz
mb	Millibar
MF	Medium frequency 30 -300 kHz
MPT	Ministry of Posts and Telecommunications
MVDS	Multipoint video distribution system
mV/m	mVolt/metre (field strength)
NPL	National Physical Laboratories
NTL	National Transcommunications Limited
OFDM	Orthogonal frequency division multiplex
OIRT	International Organization for Radio and Television
PMG	Postmaster General
SMATV	Satellite master antenna television
SHF	Super high frequency 3.0 – 30 GHz
SVF	Site variation factor

TAC	Television Advisory Committee
TCA	Terrain clearance angle
TIREM	Terrain-integrated Rough Earth Model
TSC	Technical Sub-committee
TUC	Trades Union Congress
UHF	Ultra high frequency 300 MHz – 3.0 GHz
URSI	International Union of Radio Science
VCR	Video cassette recorder
VHF	Very high frequency 30 – 300 MHz
VLF	Very low frequency 300 Hz – 3 kHz
VRP	Vertical radiation pattern

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CCIR (Geneva)

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Chapter 2, Figure 4: Ibid.

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Chapter 2, Figure 7: Obtained from RD Report 1986/4 (Ref. 2.25)

Chapter 2, Figure 10: Obtained from RD Report 1991/11 (Ref. 2.24)

Chapter 3, Figure 2: Obtained from RD Calibration Manual (Ref. 3.6)

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Introduction

There were three main reasons for starting the project described in this thesis. Firstly, the author believed that some of the broadcasting developments which had taken place during the Twentieth century did not make the best use of the resources expended on them. In part this was due to lack of evidence, and the author's second reason was to carry out further research on experimental results which he had helped to produce during his career from 1954 in service planning. Thirdly, with enormous changes in broadcasting initiated at the end of the century, he was concerned that some of the planning methods to be used, in part still based upon earlier work, were inadequate. In consequence, the results achieved using these techniques might fall short of the ambitious objectives.

The thesis contains six chapters, and the first is a history of the evolution of the terrestrial broadcasting networks in the UK. It concentrates upon the scientific and technological aspect, but by describing social and political pressures, it also illustrates how those factors influenced a new generation of engineers developing a novel system. Responsible for designing a medium which had to be transmitted by radio waves through virtually unknown space, their pragmatic investigations into the all-important subject of propagation had to take account of ongoing scientific work, which was largely based on established nineteenth-century research. There were occasional worrying disparities in attempts to reconcile their new evidence with these entrenched theories, and these problems increased as their work moved up through the frequency spectrum. Unfortunately, lack of research effort meant that some of these anomalies remained unresolved. Then, of course, in designing their new systems, the engineers had also to achieve the various objectives for the coverage of the services, set by their administrators and the politicians. This became a major preoccupation, often demanding fundamental changes to plans based upon technological factors. Because radio waves are not limited by administrative boundaries, all these developments were of interest to many national and international organizations, and the chapter reveals how the whole process became a complicated series of individual investigations progressed (or obstructed) by negotiations involving many disciplines. The

apparently successful broadcasting networks that were achieved were the result of remarkable engineering enterprise, but by the end of the century serious new challenges were emerging.

The second chapter describes the introduction of the planning methods that could be used internationally so that each country could proceed with the implementation of its own broadcasting networks. From this point in the thesis the work concentrates upon the television and sound radio developments in the very-high and ultra-high frequency bands above 90 MHz, because these were the services that were to establish broadcasting as a major feature of everyday life. Thousands of new transmitting stations would be needed, with substantial demands for all sorts of resources. The need for international consensus in the planning stages was clear from the outset. Agreement on the field strength prediction technique and other planning parameters to be used was vital if the spectrum was to be efficiently allocated. There was relatively little reliable information, but a simple method had to be quickly agreed, and the recommendation specifying the planning standards was produced in 1952. Inevitably, rapid technical progress within some countries subsequently revealed certain deficiencies in the recommended parameters, and the chapter lists a number of significant criticisms. However, having obtained total international agreement at an early stage, it was virtually impossible to introduce anything other than fairly minor modifications, and important parts of the original recommendation continued virtually unchanged to the end of the century.

Continuing the appraisal of past work, the third chapter reports that although little could be done about improving the international planning method, there was an urgent need for more precise predictions for use within national boundaries. Whilst the simple international method could be used at planning conferences to estimate the risk of interference from transmitters in adjacent countries, thereby establishing the frequency assignments and approximately quantifying the need for power restrictions, much more accurate methods were needed to define the extent of the wanted field strength – the coverage of each transmitter. The pin-point positioning of a transmitting antenna, its exact radiation pattern, the polarization, and its precise operating frequencies, demanded detail if resources were not to

be wasted. The question of precision is dealt with at some length in this chapter, and various prediction techniques have been examined. The introduction of empiricism to improve accuracy is also dealt with at this stage. Early methods had been based upon optical ray theories, and the availability of extensive terrain databases and comprehensive computer facilities meant that complex mathematical treatments of these techniques could be explored. But the results were not impressive. Perhaps time pressures demanded that some researchers were more concerned with the development of the mathematics, rather than seeking new physical explanations for measurements which conflicted with the theories. Then the feedback principle surfaced, and methods were "adjusted" on the evidence of measurements. In some cases this went too far – the original theories formed a somewhat ramshackle skeleton of osteoporotic bones, covered with an extensive wardrobe of empirical adjustments. However, towards the end of the century the emergence of new ideas, and much improved computer facilities prompted a further attempt to achieve worthwhile improvements in the international method. The author was closely involved in a working party to pursue these ideas, but although technical consensus was achieved, little real progress was made. This was a variety of reasons for this, but importantly the imminent prospect of digital transmission was an effective deterrent to any new proposal to abandon the old, long-accepted methods.

Chapter 4 departs from the analysis of past methods and describes the results of the author's own investigation into the research material. This was done for the second and third reasons mentioned in the first paragraph of this section, both strongly endorsed because it was believed the problems implicit in the broadcast changes that were being proposed at the end of the Twentieth century would demand standards of coverage assessment not achieved before. These changes involved the move from analogue to digital modulation for many thousands of television transmitting stations, all in operation and all occupying the same parts of the frequency spectrum.

The Chapter 4 review started, importantly, with a complete reappraisal of the many thousands of measurements which had been assembled by the author, because it was believed that propagation had

been described in the past using occasionally questionable statistics to define variation of field strength in time and space. In particular, the effects of the troposphere had been broadly quantized in terms of the effects of refraction, but there was virtually no evidence relating past field strength measurements to co-existing upper air data. Pursuing a different approach, the author was convinced that the comprehensive surface meteorological reports produced four times daily for the UK could provide more information describing the behaviour of the troposphere, and its effects on propagation. Unfortunately, these records only existed as hard copy, and much processing was required to obtain a significant sample, but this did demonstrate that the movement of weather patterns over the UK, revealed by the surface observations, provided a reliable statistical illustration of the incidence of abnormal propagation conditions. This led to the revision of an empirical prediction, introduced by the author during the work described in the previous chapter, which was then used for further work in the project described in the next chapter.

In the fifth chapter, the subject of the analysis of coverage is reviewed, for which new estimates of the existing television service of the UK have been produced, using the author's revised prediction. Uniquely, these estimates have then been compared with the number of complaints received by the various authorities from viewers concerning the quality of reception, feedback which was never available in the past. The correlations between the incidence of abnormal propagation and the volume of complaints supported the technique of employing the surface meteorological data as a means of predicting the risks of interference. Unfortunately it was not possible to extend the same techniques to the developing digital services. These are still under development, and although new planning parameters have been agreed, frequency plans have yet to be completed. Nevertheless, the new propagation information obtained during this project suggests that the risks of interference to terrestrial digital reception in the UK may be higher than those forecast using the most recent international prediction method.

The final chapter presents conclusions drawn by the author, and suggestions for further work. The

conclusions are largely confined to technological areas, although the influence of political decisions, and in some cases the lack of them, is mentioned. The enduring overall conclusion is that the relatively low priority awarded to research into the use of the radio frequency spectrum during the century certainly affected broadcasting development, and necessarily, many other communication projects. Future prospects are uncertain, but immediate indications are unfavourable. The priority is to achieve a result within a time scale, not necessarily making the best use of resources, but leaving the consumer to select what he wants from a prolific market. The suggestions made for further work are intended to adjust the balance, and perhaps reveal the true costs.

1. An Historical Review – Science and Technology v. The Rest

1.1. Summary

This first Chapter is a history of the development of the UK broadcasting transmitting network – an important component of a medium which was introduced early in the Twentieth century and which eventually served virtually the whole population of the UK. Broadcasting is a process which can be seen as a chain, in which the replication of a performance in a studio passes through a sequence of operations to a distant receiver. The designs of the individual links in this chain determine the technical quality of the reproduction, and where the signal has to pass through the space between the transmitter and the user's receiver, the uncertainties of radio propagation arise. It will be seen that the medium made heavy demands upon a limited radio frequency spectrum, and the need to use this efficiently increased as the number of transmitters increased. Regrettably it is true to say that despite its importance, research into propagation has not always been adequately resourced, and there is good reason to refer to this as the weakest link in the broadcasting chain.

As well as dealing with the technical problems, the design of the transmitting network has had to meet the political and social demands which have evolved during the century, as the full scope of broadcasting was revealed. All sorts of requirements emerged which influenced the technical specifications of the equipment required to transmit and receive the broadcasts. In reporting the history, this first chapter describes the overall evolution of the UK broadcasting network through the century, illustrating the ways in which a relatively small group of engineers and scientists dealt with constantly fluid objectives, and this explains the perhaps provocative title.

1.2. The Electromagnetic Theory - The Basis of Radio Network Planning

The efficiency with which a radio network can be built and the achievement of its coverage objectives depend very largely upon the precision of propagation prediction. Plans for the siting and for the operational specifications of many hundreds of closely-spaced transmitting stations have to be prepared at an early stage in order to negotiate frequencies, estimate costs, assess the environmental problems, and purchase the land required. Ultimately the users - the listeners and viewers - must be satisfied with the technical quality of their reception. All this is placed in jeopardy if the quality of the signal in its passage through space cannot be forecast.

The scientific theories which led to the development of radio emerged from the classical work on electromagnetic radiation which took place in the nineteenth century. The mathematical basis of electrostatics and magnetostatics had been outlined earlier, but the implications of electromagnetism were not deduced for some years. Prior to the development of the electromagnetic theory, investigations of the transmission of energy through space were concentrated upon the optical range. Belief in the "elastic-solid" theory was entrenched, and it was assumed light was transmitted by means of transverse waves through an all-pervading material ether. Despite flaws in this theory, the concept of a contractile medium did to some extent explain the complicated behaviour of light waves, and retained substantial support in the scientific community for many years.

The foundation of the science of "electrodynamics" by Ampere, which was to become electromagnetism ^(1.1), was followed by Faraday's early work on electromagnetic induction. His somewhat impromptu lecture at the Royal Institution in 1846 ^(1.2) summarized his conclusions on the nature of atoms and their association with lines of electric and magnetic force, suggesting that these were the medium whereby light was propagated.

It was James Clerk Maxwell who drew together the results of all the previous work to produce his mathematical theory of electromagnetism^(1.3, 1.4). Maxwell showed that electric and magnetic forces were transmitted by transverse waves, and the velocity of propagation was that of light. This led to the conclusion that light is an electromagnetic or radio transmission, although his somewhat intricate mathematics still failed to convince many of his colleagues. His main conclusions were expressed in four equations, which related to radiation in free space, and he went on to deduce the boundary conditions which exist when these dynamic fields encountered a conducting surface.

Maxwell's work was almost entirely theoretical, and it was more than 20 years before Heinrich Hertz carried out his successful practical experiments which validated the mathematics^(1.5, 1.6, 1.7). He verified the existence of electromagnetic radiation in air employing the principle of standing waves within the confines of the physics laboratory of Karlsruhe University. These successful experiments convinced the scientific world that the electromagnetic theory provided an explanation for the transmission of electrical and magnetic energy. Support for the elastic-solid medium faded away, although in the twentieth century, of course, the development of the quantum theory witnessed a return to a form of corpuscular propagation, when it became clear that the electromagnetic concept did not provide a full explanation of the radiation of energy over the entire frequency spectrum^(1.8). Experiments carried out on black body radiation did not reveal an indefinite increase of energy with frequency, predicted by the strict application of the theory. The solution to this anomaly was reported by Planck^(1.9), leading to the conclusion that around light frequencies, dualism between wave and corpuscular theories exists. The photoelectric effect provided another example, where it was demonstrated from the work of Bohr, Rutherford and others that the measured energies of photons emitted from surfaces by light were incorrectly predicted by the electromagnetic theory.

It was concluded at the time that as long as a particular investigation concerned interaction of light with light, e.g., in interference or diffraction calculations, the electromagnetic theory adequately explained the facts. Where light affected matter, such as in the emission and absorption of light,

then problems occurred when wave calculations were used. However, these difficulties apparently occurred high in the spectrum, very substantially above the range of frequencies used for broadcasting. For most practical purposes, subsequent studies concerned with developments up to about 2.0 GHz demonstrated that the wave theories provided an adequate explanation of propagation behaviour, and they have formed the backbone of prediction methods used in the introduction of broadcasting networks. It has been assumed that the nature of the transmission of energy through free space is largely independent of frequency, whilst the frequency-sensitive influence of factors such as dispersion, diffraction, reflection and refraction could be predicted on the evidence of optical experiments. Unfortunately this geometrical ray approach occasionally produces serious errors, usually attributed to the problems of quantifying all the factors which affect the calculation, notably the detail of the propagation path. As a simple example, the amount of energy absorbed or reflected when an indirect ray contacts an intervening surface, and the effects upon its phase relative to the shorter direct path between the terminating antennas, hints at the need for many assumptions. Development has consisted of providing more data, and increasing the complexity of the prediction, but as will be seen, fundamental problems remain.

1.3. The Introduction of Radio (1890 - 1920)

By the time of the experiments of Hertz, electrical telegraphy was an established technology providing world-wide communication through a vast network of wires. Within Britain, telegraphs were developed initially by private companies, but they were taken over by the Postmaster General (PMG) in 1868, becoming a Government monopoly a year later. The invention by Bell of the telephone in 1875 transformed the telegraph service in the USA, but its introduction to Britain was delayed for five years by the General Post Office (GPO), wishing to preserve the monopoly against private incursion. Even when the courts decided the "telephone was a telegraph", progress in Britain was slow until the GPO absorbed the service in 1912.

As a serious competitor to the vast telegraph interests, the advent of radio or "wireless" transmission at the end of the nineteenth century was of enormous significance. Many predictions of its future were produced, and probably those published by Crookes^(1.10) showed the greatest prescience. Curiously, however, there was apparently something of a lull in progress following publication of the Hertz experiments, and it was not until his early death in 1894 that there was renewed interest in his work^(1.11). There had been substantial parallel research in various countries into the means of detecting Hertzian waves, but it was probably a lecture by Lodge to the Royal Society in 1894 which focused international interest on the developing technology^(1.12). Two naval men - Jackson in Britain^(1.13) and Popov in Russia^(1.14) - both devised wireless telegraphy systems for the transmission of morse signals from ships, and Marconi in Italy began a series of simple experiments that were eventually to lead to the introduction of broadcasting^(1.15). However, failing to attract sponsorship in Italy, Marconi came to London in 1896 and two years later secured his first commercial contract - the installation of a 12 km. link between Rathlin Island and Ballycastle in Northern Ireland for the transmission of weather forecasts for Lloyds. During the final years of the century Marconi demonstrated his wireless equipment to many interested organizations, and this led to the employment by both the army and the navy of rudimentary equipment during the Boer War^(1.16, 1.17).

In 1900 the Marconi International Marine Communications Company Ltd. was formed, and Marconi announced that he would build stations to provide a transatlantic link. This was regarded with astonishment, because up to that time the transmissions, mostly confined to the medium frequency (MF) band, had not been received at distances beyond 300 km, although early work on the propagation mechanics of the surface wave by Sommerfeld and Goubau had forecast its ability to travel around the curvature of the earth. Gauss had long before proposed that an electrically-conducting region above the earth might be the reason for observed changes in the terrestrial magnetic field, and in 1892 Balfour-Stewart had surmised that an ionised reflecting layer might exist^(1.18).

Marconi's tests carried out in December 1901 between Poldhu in Cornwall and St. Johns in Newfoundland have been well documented ^(1.19, 1.20). The important parameters needed to investigate the propagation conditions were unknown at the time, but a recent investigation by two American researchers has placed the frequency at between 475 and 540 kHz, and although the total power was about 1.8 kW, much of the energy was distributed above this frequency range ^(1.21). Discussion followed the experiment, and a contemporary explanation that transmission was achieved by diffraction was dismissed by Lord Rayleigh. The recent American study concluded that reception was achieved by single-hop reflection of the sky wave, and work in 1902 by Kennelly in the USA and Heaviside in Britain explained the long-distance transmission as being due to the presence of a conducting region above the earth, although hard evidence for this did not appear for many years. Subsequently Marconi developed new equipment designed to work at much lower frequencies, using larger antenna systems. He discovered this led to improved reception and his transatlantic link using a new large site near Clifden in Ireland was opened in 1907 using a frequency of 45 kHz.

In the first years of the new century Marconi foresaw no need for voice transmission, the Morse code being adequate for communication between ships and across oceans, and he pursued this technology until about 1912. It was left to others, notably Tesla, Fessenden and de Forest to examine the possibilities of speech communication, which involved the use of continuous wave (CW) transmission ^(1.22, 1.23). By 1906 a high-frequency (HF) alternator had been produced, and was introduced to Fessenden's transatlantic service working on 75 kHz between Massachusetts and Machrihanish in Scotland. This was claimed to mark the beginning of pure CW transmission ^(1.24).

The early work on transmission systems was accompanied by equally important developments at the receiving end. Until 1900 transmitters and receivers were untuned. Oliver Lodge had identified the principle of tuning ^(1.25, 1.26), but it was the invention of the diode valve in 1904 which really provided the basis for concentrating the energy of individual transmissions into discrete channels. The developments of vacuum techniques and the invention of heterodyne, regenerative

and superheterodyne receivers over the years between 1902 and 1918 enormously enhanced the value of the radio spectrum.

Whilst there was considerable interest in the development of transmitting and receiving equipment, research into propagation commanded low priority. The main objective was to obtain commercial contracts in a relatively small but growing market, and this was satisfied by a process of trial and error rather than prediction. Some field strength measurements were made over short distances at frequencies around 2.5 MHz in 1905^(1.27), and the differences in range between day- and night-time transmission were noted. The influence of ground conductivity upon the strength of the signal was also first observed at the Marconi site at Clifden, which was situated in a bog^(1.28).

The development of radio communication primarily for marine use proceeded rapidly, although progress was hampered by international rivalry between the Marconi Company and Telefunken in Germany. This led to the first international conference - the Preliminary Conference on Wireless Telegraphy - convened by the German Government in Berlin in 1903. A second conference, the Radio Telegraph Conference of Berlin, followed in 1906, which marked the first allocation of frequencies. Two frequencies - 500 and 1000 kHz - were allocated for public correspondence, and the band between 188 and 500 kHz was reserved for services "not open to public correspondence", mainly military and naval. A third radio conference was held in London in 1912, by which time standards of transmission and reception had improved considerably^(1.29). Public interest in wireless had also been generated by incidents such as the Crippen case in 1910, and the Titanic disaster in 1912. But it was to be the First World War that really stimulated the eventual development of broadcasting.

The vulnerability of hundreds of miles of telephone wires exposed to battlefield conditions in the 1914-1918 war led to the introduction of small portable wireless sets with low antennas. Hundreds of thousands of young soldiers were brought into direct contact with troublesome but life-saving radio equipment, and they took these experiences with them when they returned to civilian life.

Home construction of receivers became a dynamic hobby, and enjoyed mass popularity for the next decade or more, competing with gramophone and cinema developments. A few broadcast transmitters were set up by manufacturers hoping to encourage public interest, and these were joined by amateur stations. Books and magazines were published with constructional information, and kits, such as the J. L. Cartwright "Makurone" wireless apparatus appeared on sale^(1.30). There was a market for war-surplus wireless equipment and components, including the newly-introduced valve sets. These were relatively complex but gave a superior range, whereas the crude crystal receiver which needed no power could only pick up local stations. Furthermore only one or two people could listen through headphones, unless the signal was very strong, allowing the phones to be placed in a large bowl and so radiate the sound.

Thus twenty years after Marconi's first long-range experiments substantial public interest had been created in a new medium. The foundations of a dynamic industry had been established in most of the larger countries, their Governments had been alerted to the potential, and opportunities for investment were opening up.

1.4. The Start of Public Broadcasting (1920 - 1926)

The Marconi company opened an experimental long-wave transmitter at Chelmsford in Essex in 1919, coinciding with the establishment of their research group which importantly included the subject of propagation in its mandate. A brief nightly news service started in 1920, and a performance by Dame Nellie Melba was transmitted on 15th June, 1920, cited as the first widely-advertised programme to be broadcast in the UK. This was received as far away as Newfoundland and Persia^(1.31). However, confusion was developing in the national broadcasting scene. In addition to the Marconi operation, other stations were being planned by electrical firms such as the Radio Communication Company, the Western Electric Company and Metropolitan-Vickers, and many more were being proposed by amateur broadcasters. Legally, government control of the situation was vested in the PMG, but by 1921 the Post Office was overwhelmed with applications.

A chaotic situation developed in the UK, despite the example of the haphazard development which had taken place in the USA during the War. Unhampered by the European hostilities, the American radio market had taken off, and true to the free-market traditions of the country adopted a commercial approach in which advertising was used to fund the broadcasters. Washington had virtually no control over the explosive development. Herbert Hoover declared that "it was inconceivable that we should allow so great a possibility for service to be drowned in advertising chatter"^(1.31).

Having received reports during the winter of 1921/22 of the chaotic American scene, the PMG of the day - Frederick Kellaway - was determined that development in the UK should not follow the same path. He subdivided the country into nine areas, and proposed licence allocations should be awarded for stations to serve each of these. His list contained London, Cardiff, Birmingham, Manchester, Newcastle, Glasgow, Edinburgh, Aberdeen, and Plymouth or Bournemouth. He stipulated that applications would only be accepted from British wireless manufacturers, and advertising would not be allowed. To satisfy objections from the newspaper proprietors, he also decided that only previously-published news should be transmitted. His rigorous attitude to the new medium was stiffened by the opposition from military and naval users of wireless equipment, who expressed the opinion that broadcasting by civilians would hamper "genuine experimenters, and could not be regarded as being in the best interests of imperial defence."^(1.32)

The situation was further clarified during 1922. The Marconi Company was granted a licence for a transmitter at Chelmsford (call sign 2MT) which broadcast regular transmissions for half an hour a week. A second station was sited at Marconi House in London, allocated the call sign 2LO, and was licensed to make experimental transmissions on a frequency of 840 kHz with a power of 1.5 kW. Discussion took place between the various communication companies and the government concerning the foundation of a public company to oversee the provision of a national broadcasting service. On the 23 May 1922 the GPO presented proposals and negotiations concluded on the 18 October with the first meeting of the British Broadcasting Company (BBC)^(1.33). Most of the

authorised capital of the new organization was subscribed by the major communication companies, whilst income for a three-year period was to be derived in part from a ten-shilling licence fee, and partly from royalties paid by the member firms on receivers made by them, which carried a "BBC approved" stamp. The use of this equipment involved the payment of a higher licence. Advertisements for senior staff appeared, and amongst those appointed was the general manager, John Reith, much later described as one of the "two greatest public moralizers of the twentieth century"^(1.34). Certainly he impressed the stamp of his interpretation of public service broadcasting upon the medium for many years to come.

Several of the engineers who had worked in the Marconi Company on the development of broadcasting transferred to the BBC, and their first objective was to set up a basic plan to cover the country with nine 1.5 kW MF transmitters, having assumed responsibility for those already in operation in London (2LO), Birmingham (5IT) and Manchester (2ZY). Programmes, lasting about four hours daily from these three stations began in November 1922, further transmitters were installed at Newcastle, Cardiff, Glasgow, Aberdeen and Bournemouth in 1923, and in the following year a service was started in Belfast. These stations had powers of about 1.5 kW, and a daytime ground-wave range of about 20 miles. After dark the service areas expanded considerably^(1.35).

In 1924 the coverage was extended by adding ten low-power relay stations, each linked to a main station by GPO land lines, and this brought about 65% of the population of the UK within range of the service. The use of links meant that news bulletins read in London could be broadcast simultaneously throughout the network, first tested in December 1922 and taken into regular use from May 1923. Previously the service was effectively a regional system, because programmes were produced in London, Birmingham and Manchester for transmission by the local transmitter. The introduction of interconnecting land lines provided a national facility^(1.36).

The final step in the development of the Company's service was taken on 27 July 1925, when a second programme was brought into operation using a 25 kW low frequency (LF) transmitter at

Daventry (5XX), increasing the population coverage to about 80%^(1.36). The extensive coverage of this single station, which duplicated much of that already provided by the MF installations, became the national programme, allowing the the MF network to be developed as a regional service.

Most early transmission systems were based upon the elevated wire antenna^(1.14), and this became the basis for Marconi's projects over the next 30 years. A modified version, the suspended long wire antenna, was useful for long-distance transmission, having the ability to concentrate the radiated power in a relatively narrow beam. However, this directional property was not ideal for the broadcast service, which generally demanded omnidirectional transmission from sites selected to be in the centre of target service areas. Broadcast engineers developed mast radiators providing vertical polarization, and the use of frequencies in the MF band meant the dimensions were practicable. Much work was done on antenna research^(1.37, 1.38), although early design work was empirical, and theoretical exploration often took place after the antenna had been developed. This was one reason why the period saw the initiation of systematic field strength measurements, because these were needed to adjust the design of the antenna. It was soon appreciated that these measurements also provided a quantitative assessment of the extent of the service area.

Throughout the Twenties arrangements proceeded for the technical administration of radio developments. In 1920 the Radio Research Board, a branch of the Department of Scientific and Industrial Research (DSIR) was set up, and they established a research station at Slough^(1.39, 1.40, 1.41). Early results from these professionals confirmed observations from amateur researchers that favourable propagation conditions existed at frequencies above 3 MHz, and the very low frequency (VLF) Empire Communication System being developed by the Marconi Company was abandoned in favour of a high frequency (HF) system^(1.42). The International Union of Radio Science had been established (URSI) in 1919, but it was not until 1927 that the important International Radio Consultative Committee (CCIR) was formed following the Washington Radio Conference, its prime responsibility being the co-ordination and documentation of technical matters between Radio Conferences. Also established during this period was the International Broadcasting Union (IBU),

an assembly of specialists who concentrated on the needs of their profession. This was to become the European Broadcasting Union (EBU), and although less prestigious and formal than the CCIR, in later years this smaller organization carried out a great deal of vital specialized research that was subsequently accepted worldwide. Centred mainly on Western Europe, later the EBU was paralleled by the International Radio and Television Organization (OIRT), which co-ordinated work within Eastern European countries.

At this point it is necessary to describe briefly some of the political manoeuvrings surrounding the development of the BBC in these formative years. The internal management arrangements of the Corporation and the relationships with the Government then established were to have profound effects upon the objectives and the technical design of the transmission network.

From the outset much depended on the working relationship between the single-minded Reith and the sometimes authoritarian PMG. Difficulties first arose in 1923, when there was disagreement over licensing arrangements, and in 1925 there was more aggravation, complicated by looming national unemployment. These early disputes with the Post Office were to create enduring suspicions within the BBC about the motivations and actions of the department which effectively controlled its income.

The problems in 1923 led to the first official inquiry into broadcasting, carried out by the Sykes Committee. The BBC immediately objected to the outcome, which reduced its income, but after a personal battle by Reith, a compromise was reached. Broadcast advertising was rejected by the Committee, although the PMG sanctioned certain sponsored programmes and commercial information, and in fact several concerts organized by various newspapers appeared over the remaining years of the company's operating licence, which the Committee's report confirmed should be reviewed on December 31 1926.

During 1925 both external and internal difficulties occurred. The former, which led to the second inquiry into broadcasting, was provoked by a bill presented by the PMG confirming the authority

of his department to control the ether and to collect broadcasting revenues. This brought an outburst from Reith which led to the rejection of the bill and the establishment of a committee led by the Earl of Crawford ^(132, 133). Their report in March 1926 initially satisfied Reith; it proposed closure of the BBC as a company, and recommended a public corporation with the security of a ten-year Royal Charter, funded by the licence fee. He saw this as freedom from the commercial problems which had been experienced with the radio manufacturers, whilst maintaining the monopoly of the BBC. However, although the outcome was a personal victory for him, and broadly satisfactory for broadcasting, it was achieved at the cost of some ill feeling within the BBC between the executive Board of Management and the Board of Governors, who felt they had been side-stepped in the negotiations. Characteristically Reith was not disposed to proceed by consensus because this meant distorting his vision of the future of broadcasting. The dichotomy between the executive and the Board of Governors was the first of many that surfaced throughout the subsequent history of the BBC, and some have been the cause of serious internal dispute.

The experiences of the closing months of the BBC as a company proved to be vital. The general strike affected all branches of industry, including the newspapers. In the days leading to the event, the papers assumed that whilst they would close, broadcasting would continue, and would be the Government's mouthpiece. The Trades Union Congress (TUC) blacklisted the BBC, and the public were advised to pay no attention to broadcast announcements, which would present Government propaganda. Reith saw this as an opportunity to reveal a fair and unbiased output, and although some of the announcements were needlessly melodramatic, he succeeded. Thus for a brief period the BBC was the lone voice in the public arena, it made the Government and others appreciate the potential power of broadcasting, and secured its future.

1.5. The Expansion of Radio and Introduction of Television (1926 - 1939)

Although substantial coverage of the public service broadcasting networks was achieved within the first four years of the BBC, there was an increasing number of complaints from listeners

concerning reception interference. Most of the engineering effort had concentrated on providing services, they now had to improve the quality for an increasingly discerning audience. In this context, it is interesting to quote from the pamphlet by P. P. Eckersley, the chief engineer^(1.35).

“It is considered that degree of service is a function of the clarity with which a programme can be heard. The degree of unwanted interruption to the programme is the degree of failure to give service. The majority of listeners in all countries find their continued interest in broadcasting due to what they hear, not the means by which they hear it. If what they hear is variable in strength, frequently distorted and accompanied by a background of extraneous noises, their enjoyment comes from causes for which the broadcasting engineer cannot hold himself responsible in any way. We are here concerned with broadcasting, not the art of fishing for microvolts in the eddies of the ether. The excellence of the transmitting service at a given point must be expressed quantitatively as a ratio of wanted signal field strength to interference field strength....”

Eckersley was aware that many listeners were amateur radio constructors, happy to fiddle with their cat's whiskers and to find fulfilment in the reception of any noise resembling a broadcast transmission, but in his last sentence he stated the basis of future coverage planning, whereby the quality of the signal required by the user should be numerically defined. In his pamphlet he reviewed the early planning methods and surveyed the prediction methods then available, having already specified the field strength values needed for various grades of reception quality^(1.43). Thus a Grade 'A' service would be provided given a field strength of 10 mV/m (80 dB relative to 1 μ V/m or dB μ), Grade 'B' required 5 mV/m (74 dB μ), and marginal Grade 'C' reception quality would be available with 2.5 mV/m (68 dB μ)¹. Whilst specific, these standards could only be applied approximately, due to the very basic means and methods of field strength measurement then available. Initially the BBC had only one van available for the work, measurements had to be made whilst the vehicle was stationary, and in order to protect its fragile contents, maximum speed on open, metalled roads was limited to 40 kilometres per hour.

The coverage situation was complicated by a decision of the IBU following its first meeting, held in London in 1925. They reported that the rapid growth in the number of transmitters within

¹ Although expressed in mV/m until about 1950, the more convenient decibel unit is used from this point.

Europe was creating intolerable levels of mutual interference. The most obvious step was to limit the co-channelled assignments, and a meeting of the Union in 1926 agreed a provisional frequency assignment plan, involving a reduction in the number of channels already used by the BBC. This stimulated efforts within the Corporation to economize frequency usage, and experiments using the ten low-power transmitters on 1040 kHz demonstrated the value of common-frequency working, a system whereby synchronization of the frequency of transmitters carrying the same programme material reduced co-channel interference levels ^(1.44). However, although this technique saved frequencies, it affected regional planning, because co-channelling created a "mush" area between each synchronized transmitter, which then had to be served by another station. Thus it was often used to provide frequencies for relay stations, and resulted in some curious arrangements in the MF plan. For example, Brighton, Folkestone and Bexhill, although in the London Region, were not served by the high-power station at Brookmans Park, and had to have relay stations radiating the West of England programme in order to share the frequency allocated to the high power transmitter situated at Clevedon in Somerset ^(1.36).

Propagation information was steadily accumulated, and to co-ordinate the broadcasting measurement activities a "field strength" section was established within the BBC Research Department. Primarily concerned with surveying new service areas to check the performance of the transmitting antennas and the extent of coverage, it also began to assemble results for comparison with propagation theory. The attenuation of the ground ray with distance, set out by Sommerfeld ^(1.45) was adapted for broadcasting use ^(1.46). The decay of field strength was described in terms of "numerical distance", a factor quantified by the earth's conductivity, wavelength and the length of the propagation path. Attenuation as a function of distance curves were produced and checked by an extensive series of measurements. Additional losses caused by buildings and vegetation were also estimated from the results.

Meanwhile, Professor Appleton at the Radio Research Station provided new information concerning the temporal fluctuations both in height and density of the Kennelly-Heaviside layer.

Reflected from this layer, indirect rays returned to earth and interfered with the ground wave. Data concerning the ratio of the indirect to the direct ray was also obtained from the USA ^(1.47). Using some fairly coarse assumptions, including one which put the average measured value of the indirect ray after a single reflection at about 40 dBμ for 1 kW effective radiated power (ERP), the information was used to quote fading ranges, and hence likely service limits. Eckersley conceded that the calculations took on a "rough and ready character", but were "essential to the engineer mapping out a new scheme of distribution of transmitting stations" ^(1.35).

This period marked the onset of the diatribe that has continued ever since amongst spectrum users for more frequencies. In his 1929 pamphlet ^(1.35) Eckersley produced an argument that the broadcasters should be allocated frequencies at the lower end of the spectrum - the long waves - because these provided relatively large service areas. Other users, he argued, e.g., marine and aeronautical interests, could be awarded higher frequencies - *"It seems wrong to allocate waves for oversea transmission that are ideal for direct-ray broadcasting service overland, and waves for overland transmission that are superlative for oversea communication!"*. He also argued for a narrower bandwidth for telegraph services, thus a separation between assignments of 0.5 kHz was perfectly adequate for these transmissions, leaving the wider allocations of 10 kHz for the broadcasters. However, his arguments failed to win any favour with the Government, and with the exception of the 200 kHz assignment for Daventry (later Droitwich), the domestic broadcasting development proceeded in the MF band.

Transmitter and receiver growth during the period was largely dependent upon the development of the thermionic valve. By 1929 higher transmitter powers became feasible, and many twin high-power 50 kW installations replaced the early 1.5 kW. One of each pair radiated the National Programme - largely produced in London - whilst the second transmitted the Regional Programme. Throughout the Thirties the construction programme continued until by 1939 the National Programme was being broadcast on 200 kHz by the Droitwich transmitter and by a group of three synchronized transmitters on 1151 kHz, together giving a population coverage of about 93%. A

daytime coverage of about 89% was achieved for the Regional Programmes which had a total of twelve transmitters using ten frequencies in the MF band ^(1.36).

As far as receivers were concerned, the crystal gave way to the crystal valve, then to all-valve sets and eventually to the superheterodyne. Progress in the design of home equipment rapidly accelerated, several manufacturers for the domestic market were established ^(1.48), and amateur construction declined. The number of domestic licence holders grew from two million in 1926 to just under eight million in 1939, representing 65% of the households.

To deal with the dynamic international situation, further conferences were held in Prague in 1929 and in Madrid in 1932. The latter saw the formal establishment of the International Telecommunications Union (ITU), an organization which merged telegraph and radio interests, and rules were laid down for frequency registration procedures. The upper limit of frequency allocation was extended from 30 MHz to 60 MHz. In 1933 a European broadcasting conference was held in Lucerne, which produced the basic plan for domestic stations within the zone. A total of 133 channels was listed, and a contemporary paper reported the mean power per channel of stations then in operation was 24 kW ^(1.49). This paper estimated the occasional peak value of the interference field created by the more powerful stations at 86 dB rel. 1 μ V/m. In 1937 an inter-American conference in Havana proposed the World should be separated into three planning regions for future allocation purposes, and this was adopted at the first Administrative Radio Conference which was held in Cairo in 1938.

The period also saw the installation of sound transmitters using the HF bands to provide a World service. Stimulated by the ever-active group of amateur radio enthusiasts and by the official communication links set up by the international manufacturers, interest in broadcasting to other countries had blossomed in the Twenties. The Washington Radio Conference of 1927 had assigned frequency bands from 10 kHz to 30 MHz for broadcasting, maritime, aeronautical, land mobile, point-to-point and amateur services. Frequencies were allocated to international broadcasting in

the range from 2.3 - 6.0 MHz. Within the UK a long period of discussion ensued concerning the funding of a World service ^(1.50), and following a series of experiments, the BBC 'Empire' service opened at Daventry in 1932.

Thus by the mid-Thirties considerable progress had been made in the development of national and international broadcasting services in the spectrum below 30 MHz. Importantly it had become clear that the technical processes of service planning often decisively influenced coverage aspirations. However, the situation was about to be immensely complicated by the introduction of television, entailing expansion into frequency bands largely unexplored, and involving a tenfold increase in the number of transmitting sites.

As with the introduction of radio, many people can be identified as contributors in the development of television. In 1884 Paul Nipkow suggested the use of a spinning disc into which a spiral of holes had been drilled for the purpose of scanning a scene, vertically and horizontally. This mechanical approach found no favour at the time, and it was twenty years before Campbell Swinton proposed a more promising electronic system ^(1.51). This attempt was also thwarted, because the cathode ray tube and wide-band amplifiers had yet to be fully developed, and the innovator Baird pursued the mechanical scanning technique. Virtually without commercial support he produced equipment used in experiments conducted by the BBC between 1929 and 1934. These 30-line definition pictures were transmitted from the London MF station at Brookmans Park, although because of the limited bandwidth the single transmitter could radiate either vision or sound, but not both together. Later this became possible when a second MF transmitter was added. In 1935 Baird produced a version capable of scanning 240 lines at a picture repetition rate of 25 frames per second, but the equipment was complex, demanding constant attention.

In 1931 the Electrical and Musical Industry (EMI) company backed by substantial support from American industry started to develop the electronic system, and within a year produced an impressive 150-line model. Decisions in the USA and Germany to proceed with electronic

scanning were taken, but in the UK it was not until 1934 that a committee chaired by Lord Selsdon, the PMG, was set up by the Government to choose between the options. Its report proposed a trial in which both systems would be transmitted sequentially. Astonishingly, during the preparations for this trial EMI declared that it would be using a 405 line/50 frames per second system, astonishing not least because the bandwidth demanded for transmission was approaching 300 times that so far used for the radio service. Here, however, EMI were at an advantage because a recent merger with Marconi gave them access to state of the art transmitter expertise. Prophetically, when the Marconi-EMI team had completed this phase of the project, Sir Isaac Shoenberg, their research director, declared "Gentlemen, you have now invented the biggest time waster of all time. Use it well!"^(1.52)

The transmitting and studio site chosen for the BBC television service was at Alexandra Palace in North London, and the trials opened on 2 November, 1936. The plan was to alternate each technique on a weekly basis, transmitting for two hours each day, but the mechanical equipment soon proved unreliable, and from February 1937 only the Marconi-EMI system remained in use. The carrier frequency chosen for the vision transmitter at Alexandra Palace was 45 MHz, with sound on 41.5 MHz. The carriers were amplitude modulated and the picture information was contained within a 3 MHz wide lower sideband, the upper sideband being suppressed. The maximum ERP, reached in a condition of "peak white", was 17 kW, and vertical polarization was used for the transmitted signal^(1.53).

To examine propagation conditions in the very high frequency (VHF) bands, test transmissions were also started in 1936 using a transmitter at Broadcasting House operating on 38.9 MHz, and this showed an urgent need to revise the field strength measurement techniques. At the time two types of survey were being made for LF/MF work - local and distant. The former checked the transmitting antenna performance and confirmed that there was no source of local attenuation, such as high-resistance subsoil. The latter took the form of "attenuation runs", in which field strength was recorded along a radial from the transmitter. Observations along each profile were continued

until fading caused by interference from the indirect ray occurred, and this was taken to mark the limit of service. A few other measurements away from these radials checked local conditions, and circuit noise ^(1.54). However, the shorter wavelengths were affected by reflections from passing vehicles, and diffraction behind natural and man-made obstacles was much greater. The influence of polarization was apparent, and ignition interference was a serious problem in built-up areas.

It was impossible to develop completely new measuring equipment and methods in the time available, although the survey which was carried out of the Alexandra Palace transmissions in 1935/36 did use a pen chart recorder to obtain a permanent record of field strength whilst the measuring vehicle was in motion ^(1.55). To reduce the impact of ignition interference the measurements had to be made on minor roads away from traffic, and subsequent comparison of the results of the contemporary survey ^(1.53) with one conducted some 15 years later using improved equipment revealed very significant differences, emphasizing the importance of reception site selection when assessing coverage. The attenuation run - a surviving technique from the earlier surveys - was carried out from Alexandra Palace to Thurso in Scotland, and interestingly provided early evidence of both from the troposphere, and from the E layer, although neither was positively identified at the time.

Further field strength measurements made in connection with the extension of the television service during its brief pre-war existence also led to some forecasts of the number of stations which might be needed to achieve national coverage ^(1.56, 1.57). The most optimistic suggested a network of fifteen high-power stations supported by up to 30 relay stations. However, the outbreak of war stifled all immediate action on this project, and for reasons associated with defence the UK television service closed in September 1939.

Thus at the start of the 1939/45 War the BBC domestic services consisted of a National Programme radiated by one LF and three MF transmitters, and Regional Programmes from 12 MF transmitters. A new frequency plan had been agreed at a Regional Conference held in Montreux in 1939, and

further extensive proposals had been prepared to build on this. Of course, these arrangements were cancelled when war was declared, and the conditions of the Lucerne Plan of 1933 continued, theoretically in any case, until a revision agreed in Copenhagen in 1948 was implemented.

1.6. The War Years (1939 - 1945)

As far as UK radio broadcasting was concerned, the first objective was to keep a service going, whilst devising methods of transmitter operation that would prevent enemy aircraft from using the network for navigational information. This was done by splitting the high-power transmitters into two groups - north and south - and operating each on a common frequency. Thus enemy aircraft could not tune into an individual transmitter until they were relatively close, by which time that transmitter would have closed down. This plan involved the combination of the previous National and Regional services, and the new programme was referred to as the 'Home Service'. On Government instructions, it was put into operation on the 1st September 1939. To counter the effects of local closure, and the possible impact of invasion, a network of about 60 low-power common frequency transmitters was set up by 1941, each with a range of about 15 km. In January 1940 a second programme was introduced for the "Forces".

A further development of interest to propagation studies at this time concerned the monitoring arrangements. In 1929 the BBC had set up a receiving station at Tatsfield in Kent to carry out technical checks on transmissions. The requirements expanded during the war, and a similar installation dealing primarily with foreign broadcasts and the BBC external transmissions was established at Caversham near Reading, although this installation was committed to the content of broadcasts, rather than reporting field strength data. Fortunately, some Tatsfield measurement records were retained for personal research by a BBC engineer, who used them to extend his earlier ionospheric studies ^(1.58). These later detailed records were never published, but provided some useful propagation information for this thesis.

The pre-war Empire service was substantially extended to become the BBC Overseas and European Services in 1943. Originally concentrated at Daventry, new short-wave stations were built in Dorset, Cumberland, Shropshire and Yorkshire. From two HF transmitters with a total output power of 30 kW in 1932, the service increased to 44 transmitters having a total power of 3020 kW, with another 2000 kW coming from LF and MF stations radiating foreign services.

What little broadcasting effort there was available for propagation work during the war was almost totally devoted to operational developments, and not research. However, the DSIR did continue propagation studies across the spectrum from 10 kHz up to 50 GHz^(1.59). Measurements of ground wave transmissions from 30 MHz to 3 GHz provided information concerning the effects of polarization, diffraction and ground reflection. New methods of ionospheric sounding were developed, and these refined earlier estimates of the constitution and location of ionized layers. Importantly for the work described in this thesis, the influence of the troposphere to refract radio waves was quantified in terms of its refractive index. This was determined by changes in air density and water vapour with height, but in the absence of detailed measurements describing the latter, statistics were used to define the temporal variation of a radio signal, i.e., the percentage time its field strength exceeded specific levels. This approach formed the basis of prediction methods in the immediate post-war years.

The war years saw the accumulation of experience in the development of specialized equipment by the radio industry which was to prove of substantial value to the post-war growth of broadcasting. In September 1943, in preparation for the event, the UK government set up the Hankey Committee to consider the post-war future of television^(1.60). There was emphasis on an early start, but in this respect the Committee had an impossible task, because there was no indication of developments in neighbouring countries. There had been substantial progress in the USA, and their experiences were taken into account, but in the absence of information from a war-ravaged Europe the Committee had to make a decision based upon UK preferences. Largely upon evidence from industry, these were in favour of maintaining the pre-war 405-line standard. The Committee

presented its report to Government in December 1944, which accepted the main recommendations in October 1945. At the same time the Government re-instated the Television Advisory Committee (TAC), a body originally set up to advise on the introduction of the service, but now intended to monitor future developments. Three years later under the chairmanship of Lord Trefgarne, this committee endorsed the decision to re-open the television service on the 405-line standard.

1.7. The VHF Networks (1946 - 1961)

This period from 1946 to 1961 marked the start of the explosive growth in the terrestrial broadcasting transmission network, caused by the introduction of wideband services and the transition to higher frequencies. There emerged a rapidly growing demand for research into all matters relating to spectrum and coverage planning, and most of the work for this thesis has concentrated upon the activities surrounding the VHF and the ultra high frequency (UHF) developments.

Operationally, the immediate post-war period saw the replacement of the Forces channel by the Light Programme, to which the Third Programme was added in September 1946. Restrained by shortage of money and manufacturing facilities, the television service did not re-open until June 1946, and did not extend beyond the Alexandra Palace station until 1949. By then the true scale of a national network was becoming clear. The optimistic pre-war estimate of about 45 VHF television stations had increased to at least 100, many of which would have to employ very high masts in order to achieve maximum range. Ultimately the number of permanent transmitting sites was to increase from less than 20 to more than 1300 with the opening of the UHF bands, although the implications of one aspect of the unfolding plans for these was not appreciated for some time. Each transmitter site was a valuable acquisition, the result of substantial investment of resources by the broadcaster, and by the public. It would take months, sometimes years, to acquire, pass through many planning processes, satisfying all sorts of demands, not least those of the environment. Once installed, the broadcaster was extremely reluctant to abandon any transmitter site, and in subsequent terrestrial development, e.g., the extension from VHF to UHF, would do everything

possible to develop new plans based upon use of the existing installations. The requirement to retain them became a serious constraint in service planning.

The prospect of an expensive terrestrial network encouraged a rash of proposals for alternative solutions. Arthur Clarke's proposal for an earth satellite was one possibility, but was impractical at the time ^(1.61). The Post Office Engineering Department investigated the use of a 2,000 m. mast in the London area, but this was rejected because of the dangers of tower failure in a heavily built-up area. The same organization also studied passive reflectors supported by balloons, six of which flying at 2,000 m. would cover the UK, but this was abandoned because of maintenance problems and the risk to aircraft ^(1.62). In the USA the Westinghouse "Stratovision" project was proposed, whereby an aircraft orbiting at a height of about 10,000 m provided large area coverage. The tests were successful, but the logistics were against its adoption on a regular operational basis. Thus exotic solutions were rejected, and attention was focused on the extension of the terrestrial network. Here the choice ranged from a system of high masts, high-powered stations supplemented by small relays, to a dense network of low mast, low-powered installations – the "hair-brush" approach. The former was orthodox and was adopted, although the subsequent use of the alternative by modern mobile telephones is a feature which will be mentioned later.

Detailed planning on an international scale did not start until 1947, following decisions made at a conference in Atlantic City. This was an ITU Plenipotentiary Conference, and established a new structure for the Union, including divisions to deal with the various branches of telecommunications. A new regime of radio regulation was devised with the establishment of the International Frequency Registration Board (IFRB) to record channel allocations, alongside the CCIR, co-ordinating inter-conference technical matters. This Atlantic City conference also clarified the frequency situation, the following allocations and spectrum sub-divisions being decided for broadcasting:-

VHF: 41 - 68 MHz	Band I	UHF: 470 - 585 MHz	Band IV
87.5 - 100 MHz	Band II	610 - 960 MHz	Band V
174 - 216 MHz	Band III		

Band I was assigned in the UK to the BBC for television transmission, providing enough space for five 5-MHz channels, using the 405-line standard. The first UK objective, therefore, was to plan a national service within this spectrum. This process demanded international agreement on a field strength prediction method and the planning standards to be used, the latter including factors such as protection ratios to permit co-channel and adjacent channel operation.

In 1947 little reliance could be placed on the VHF/UHF prediction methods, and in north-west European countries there were fundamental disagreements about the vagaries of VHF propagation, particularly over the seas surrounding the UK. Furthermore, although ideally a prediction should be applicable to all ranges, the international priority focused on the interference aspect and path lengths greater than 100 km. During these important early years when the basic network was established, much of the planning work was conducted by comparing the predicted interference levels with measurements of the wanted field strength. Unfortunately little research was carried out on this aspect, and experience was to reveal serious flaws in the approach. Subsequent investigations, described later in this thesis, showed that terrain attenuation affected the short-range, wanted signal but barely influenced abnormal levels of the interfering signal arriving by way of the troposphere.

Prediction developments were based upon research carried out during the war. As mentioned before, this had advanced the knowledge of the influence of the troposphere upon long-range transmission, although those specialists who persisted with mathematically challenging propagation theory found the problems of the troposphere less tangible than those they had encountered in their ionospheric studies. Their progress was hampered by the absence of hard evidence to quantify the incredibly complicated physical fluctuations in the troposphere. More pragmatic workers developed the statistical approach, whereby measurements were used to produce field strength/distance curves, i.e., graphs showing the decay of field strength with distance. Although over-simplified, these were convenient for international planning.

The BBC, the GPO, the National Physical Laboratories (NPL), and the DSIR started a series of long-distance reception/recording (LDR) experiments in 1946 to report overland and overseas propagation statistics in North-Western Europe^(1.63, 1.64). Inevitably, there was discussion between scientists probing the science and the engineers who conducted the experiments – the former had theories and the latter had results - reconciliation was sometimes difficult. The broadcast engineers who had to use the results for planning were also conscious of other problems. The essential objective was to quantify the variation of field strength not only with distance and time, but also to determine the influence of local ground cover and topography. What were the relationships between the domains of time and location? Unfortunately, although many measurements were made, research resources were very limited. For example, the BBC organized a comprehensive series of experiments, with several receiving sites widely distributed across the UK, from the Channel Islands to Shetland. In a typical month, more than a kilometre of recording chart would have to be collected for analysis at base. A team of five managed the whole project, including maintaining the sites and the equipment, collecting, analyzing and reporting the results. Before digital computers became available, the charts were analysed manually, although by the late Fifties a complex mechanical counter had been devised. Nevertheless, the ambitious programme of experiments was substantially extended over the next 30 years, eventually including UHF transmissions up to 800 MHz. The results were to be a major source of international evidence for broadcast and mobile radio development in Europe up to and beyond the end of the century.

Similarly, little work had been done on planning parameters, and the situation was complicated by the fact that countries were adopting completely different line standards; for example in France an 819-line system requiring a 13 MHz channel was being planned. This meant that because the carrier frequencies of the various systems were not identical, protection ratios needed between adjacent services required detailed international analysis. It proved to be an ongoing task. Initially protection ratios were approximated in laboratory tests using systems having the line standards of the late Forties^(1.65). Comprehensive subjective tests of interference perception were devised, and later these had to be extended as new line standards and colour transmission were introduced.

In retrospect, the allocation of frequencies to the first five high-power VHF stations to be built in the UK (London, Birmingham, Manchester, Glasgow/Edinburgh and South Wales) was lavish. All the five available channels were used, and co-channelling was avoided because so little reliance could be placed on the early planning parameters. In fact, the first serious source of man-made interference was bursts of conversation between New York taxi services, reflected from thin layers of enhanced ionization at around 125 km above the earth's surface, the so-called Sporadic E or E_s. Over time as new stations were built, this proved to be a serious source of interference, particularly to stations operating at the lower end of Band I, and television signals up to and exceeding 80 dB μ V/m were affected. Although several working parties were set up to study the phenomena, no immediate action could be agreed, and this form of interference was never formally taken into account in planning the VHF services. In practice, the allocation of Channel 1 to large stations was subsequently avoided wherever possible, and it was used for low-power stations with small service areas.

By 1948 plans for five medium-power stations had been added to serve Northern Ireland, south-west England, north-east England, north-east Scotland and southern England. It was stated that when these stations were completed (by the mid-Fifties) the population coverage of the UK would be about 88%, and plans for other stations would then follow, although it was doubted that television coverage could equal that achieved by sound radio.

Coverage forecasting remained a hazardous exercise. In the absence of interference from other stations, service area limits were defined by minimum values decided by the levels of natural and receiver noise. For the planning of the first Band I stations a minimum field strength value of 40 dB μ V/m was adopted, and this was maintained for many years, even although various forms of man-made interference, notably that caused by car ignition systems, created reception problems at much higher values. Transmitting sites were selected initially on the evidence of their topographical prominence which promised line-of-sight coverage to the target service area. Inevitably site negotiation revealed many of the prime choices were unavailable for various

reasons, and rudimentary predictions were carried out to establish the priority amongst those which were available. A site test was then conducted ^(1.66), involving the installation of temporary transmitting equipment, and if necessary a balloon was used to raise the antenna to heights up to 200 m. above ground level (a.g.l.). The transmissions were measured using a mobile unit, and results were quoted for a standard height of receiving antenna at 30 ft. a.g.l. (eventually metricated to 10 m.). Depending upon the size of the service area and the occurrence of suitable weather for balloon flying, Band I site tests would occupy between one and six months. Sometimes several alternatives had to be tested for one area, in order to find the optimum.

Occasionally, political and/or regional preferences would demand the use of a technically inferior solution. As an example, the high-power transmitter to serve south Wales was eventually situated within the Principality, whereas field tests had convincingly demonstrated better coverage could have been obtained from a site across the Bristol Channel in England. Not surprisingly environmental problems also began to surface, because transmitting installations did not improve the landscape. The choice of exposed hilltops, sometimes in areas of outstanding natural beauty, was not popular with those concerned with the preservation of the countryside, although the local population was equally vociferous in its requirement for a good broadcasting service.

By early 1951 only two of the high-power television transmitters were in operation, giving a total nominal coverage of about 23M. people. There were 586,000 combined radio and television licences, and 11,684,000 sound only licences. The slow growth in the television coverage can be attributed in part to the technical problems, but there was also some inertia within the BBC - the sound radio lobby was strongly entrenched. This contributed to the demand to improve radio reception, and some resources were diverted to investigate the use of VHF as a means of introducing a frequency-modulated (FM) service - transmission tests from Alexandra Palace were conducted as early as 1945. Such a service was already well developed in the USA, where 800 VHF/FM transmitters were in operation using an extended Band II (from 88 to 108 MHz). A network had been started in Germany, because most of that country's LF/MF transmitters had been destroyed during the war. Reception conditions in the lower bands were steadily deteriorating as

the number of transmitters grew, and a new allocation plan agreed at Copenhagen in 1948 failed to improve the position. Assignments had been made to 520 transmitters in the European area, but many authorities ignored these, including the occupying powers in Germany. Within a comparatively short time there were almost as many radio stations in illegal operation as there were in the official frequency list ^(1.36).

At the request of the PMG the TAC considered the case for VHF sound broadcasting, and in a majority report approved the coverage proposal presented by the BBC ^(1.67). This plan compared amplitude modulation (AM) and FM transmission, favouring the latter and forecasting that 51 transmitters would provide national coverage, "not as a complete substitute for long and medium wave networks, but as a powerful reinforcement of the sound services". Government approval to the FM plan was given in July 1954. With a few exceptions (notably the first transmitter which was intended to serve the London area and had its own site at Wrotham in Kent), these transmitters were co-sited with those of the developing Band I television network. In most cases the Band II service areas were predicted on the evidence provided by Band I site test measurements, although some anomalies were noted where checks were made. At the time this was attributed to polarization and frequency differences, relatively opaque factors which had received little study. The use of Band I sites complicated mast design, which had to take account of the additional wind loading imposed by the Band II antenna, and inevitably introduced more planning problems, because alternative solutions had to be examined. The situation was to be further aggravated later by the advent of commercial television.

The Stockholm Plan of 1952 paved the way for the development of the VHF bands within Europe that was to take place over the next ten years. Planning information was still extremely scarce - the propagation curves only covered distances up to 200 km, augmented by some cautious remarks concerning the incidence of abnormally high field strengths beyond that distance, especially over sea. Nevertheless, assignments for a total of 2,500 transmitting stations in the VHF bands were agreed, including provision in the UK for a second programme which would use Band III.

In 1953, the Government announced its intention to set up another public corporation - the Independent Television Authority (ITA) to provide a commercial television service^(1.68). This was to be operated within Band III, and initially this was regarded by the ITA engineers as an inferior option compared to Band I. In fact, subsequent experience demonstrated that of the frequencies allocated to broadcasting, Band III was probably the optimum. At the outset the BBC offered to run the ITA transmitter network, installing the transmitters at existing BBC sites. This offer was rejected, partly for administrative reasons, but more importantly because the propagation characteristics of the higher frequencies required new transmitting sites. The service areas which resulted were significantly different from those of the BBC, and demanded new regional boundaries, a factor of interest to the commercial programme sponsors. Annoyingly it also meant that viewers had to install a second receiving antenna, in many cases demanding different orientation and polarization from those already used for BBC services.

In September 1955 the ITA service opened from their transmitter at Beulah Hill in South London. This was barely a kilometre from the BBC station at Crystal Palace, and illustrated the difficulties of achieving agreement to the use of a single site. Many such examples of apparent engineering inefficiency were to emerge in the following years of VHF development, but public demand could not be ignored. In 1955 there were 9,414,000 radio and 4,504,000 television licences. Five years later, the situation had reversed, with 10,470,000 television and 4,480,000 radio licences issued. It soon became obvious that the VHF spectrum could not meet the public demand for television, and joint research began on the future exploitation of the UHF bands.

The search for additional spectrum was strengthened by growing concern about the 405-line standard. On the Continent 625-line definition was generally adopted, with the notable exception of France, which retained their 819-line service. The USA, geographically remote from European planning pressures, chose a 525-line system, and although this complicated later discussions concerning standardization of colour and definition techniques, it did not influence European negotiations in the Fifties. Within the UK, the TAC was asked by the Government in 1956 to comment on the adequacy of the 405-line system for the next 25 years. This led in 1957 to the

formation of a Technical Sub-Committee (TSC) consisting of representatives from the DSIR, the BBC, ITA, GPO and the British Radio and Electrical Manufacturers Association (BREMA), which set up a series of UHF tests. For these tests, both 405-line and 625-line standard transmissions were radiated from the Crystal Palace station ^(1.69). In addition to field trials, laboratory tests were also undertaken to define protection ratio results for the different systems.

From 1955 the LDR programme was substantially extended, and supplemented by field strength surveys of existing 405-line transmitters to provide information for the study of short-range propagation - up to about 100 km from the transmitter. These surveys soon confirmed a long-suspected fact, namely that there were considerable differences between the planned and actual service areas. The former had been predicted or based upon limited site tests, whereas the actual coverage evolved over a period of years. The choice of transmitter source made when each receiver was installed by the neighbourhood dealer may not have been that assumed by the broadcast planning engineer. The dealer was likely to have greater local knowledge of reception conditions than the planner. The planning engineer would have more information from his predictions concerning the theoretical risks of interference, but ultimately this was a subjective detail, influenced by local choice. There is no doubt that insufficient research during the VHF development meant that the very expensive UHF terrestrial service was planned from the outset with inadequate information.

Following the TAC studies a report was issued by them in 1958 which recommended ^(1.70):-

- the full exploitation of Bands I, III, IV and V
- the use of 625-line standards
- the eventual changeover of existing services from 405 to 625-line
- the introduction of compatible colour

This report initiated a flurry of activity within the UK, which spread to the Continent. Plans were made for a European broadcasting conference at which assignments would be negotiated for the transmitting stations expected to be taken into use over the next 20 years. In fact the basic agreement lasted much longer, and is only now scheduled to be replaced sometime around 2006. Apart from reviewing and updating the VHF networks, coverage plans were prepared for the new

UHF services. Some of these were highly theoretical, requiring many new transmitting sites and impractically high masts. Others, favoured by those who were conscious of the problems of site acquisition, were based as far as possible on the use of existing stations, and in the UK one of these (Plan "D") was eventually adopted ^(1.71). This involved the use of 64 high-power stations to serve the UK, supported by a network of an unspecified number of relay stations, each station capable of transmitting four channels, i.e., providing four-programme coverage. Importantly, this concept of co-siting offered many advantages, but it introduced problems of reconciliation between the dissimilar BBC regional and ITA commercial boundaries, established by the VHF service.

The initial planning of the new UHF networks was facilitated within Europe by the development of a new technique, a means of assigning frequencies using a simple geometrical lattice ^(1.72). This attracted a lot of attention at the time because it was ideally suited to the newly-arrived computers, and indeed it remains in use to this day for preliminary studies, but it received some opposition from more pragmatic service planners, who regarded its value as seriously diminished by excessive oversimplification ^(1.73).

The technical initiatives were noted by the UK government, and in July 1960 a decision was taken by the PMG to set up what was to become and probably remain the most extensive overall review of the medium. This was the committee led by Sir Harry Pilkington ^(1.74), which had 121 meetings between September 1960 and June 1962, when their report was submitted to the Government. They took evidence from 636 sources, including broadcasters, the industry, aspirant contributors to the industry, interested societies and organizations, religious and educational bodies, government departments, and the public. It is interesting to note that whilst much of the report was devoted to the arrangements for broadcasting in the UK, it opened with a statement that broadcasting "is dependent upon the availability of suitable frequencies", and emphasized the importance of efficient planning in the use of those frequencies. Its technical recommendations endorsed those of the TAC/TSC, including the extension of the television services into the UHF bands, the change of definition from 405 to 625 lines, and the introduction of a compatible colour system.

1.8. The UHF Development Period 1961 -1985

The frequency plans which were to be the basis of the new VHF/UHF networks in Europe were agreed at the European broadcasting conference held in Stockholm in May/June 1961, a technical committee having defined the basic planning parameters earlier that year ^(1.75). These included propagation curves, protection ratios between the many systems, and a description of the lattice planning technique that was to be used at the conference. The report by the technical committee also included proposals from 17 countries who had decided on the preliminary arrangements for their UHF networks. Of these, the UK option for a four-programme television coverage was the most ambitious, although during the subsequent conference, which included representatives from 35 countries, other administrations also increased their requirements. In the course of four weeks, assignments were agreed for 8,000 stations. Because of the scale of the work, the plans were limited to higher-powered transmitters only (ERP of 1.0 kW or greater for VHF and 10.0 kW at UHF). Certain other details, such as the precise carrier frequencies to be used by the high-power UHF transmitters, were deferred to a later meeting which was chaired by the author and held in London in 1968, by which time computer techniques had advanced considerably and these factors were quickly agreed.

Although the Conference was devoted to European development, some useful planning information came from the USA ^(1.76). However, the density of countries in Europe complicated the co-channel interference problems, and the subsequent development of international coverage planning methods has been largely based upon European results. Evidence from other parts of the World served mainly to demonstrate regional differences in propagation and coverage objectives.

The 1961 plans for the UK included proposals for extension of the VHF television and radio networks by means of a number of low-power stations, as well as the totally new projections for the UHF service. Provision was made for stereophonic transmission on VHF radio, and plans for an extensive network of 123 local radio stations, each transmitting two programmes, were also

included. It was assumed at the time that one of the two networks might be run by local newspapers, whilst the second would be operated by the broadcasters, but nothing was firm. The objective was to secure international frequency assignments to facilitate future development.

Details of the UHF television plan and the factors deciding the frequency arrangements within the UK are described elsewhere ^(1.77), and it is only necessary here to mention that the grouping of the channels which allowed for four-programme transmission from each transmitting site was chosen to minimize the risks of image and adjacent channel interference within each group. It was also necessary to take account of the interference generated by the local oscillators of UHF receivers, and by the harmonics of the oscillators of VHF receivers in the same area. However, despite increasing activity on UHF, pressure for the extension of the VHF 405 line service was to continue until 1970. Complaints from remote pockets of the country beyond the range of any form of reception had to be balanced against the obvious desire to open the new UHF services in populous areas as soon as possible. The planners reasoned that every new VHF station complicated the ultimate objective of re-engineering the whole system for 625-line operation, and in any case many believed this was unattainable. In fact, preliminary planning work in the early Sixties showed that the new planning methods gave every hope that this could be achieved ^(1.78). At the time this was thought to be a very optimistic forecast but it proved to be an accurate assessment

Initially the technical data agreed for international spectrum planning ^(1.75) were used for national developments. Much of the propagation information was transferred in 1963 to CCIR Recommendation 370 ^(1.79), which was to become a vital reference for international planning. Originally introduced in 1951, it has been the responsibility of one of the ITU/CCIR group of international specialists concerned with propagation in non-ionized media. The Recommendation has been substantially extended throughout its history, but much of the basic information, including many of the all important propagation curves, has remained virtually unchanged since 1963. Its origins, and the evidence upon which the parameters are based, are therefore of fundamental interest to this research, and are examined in depth later in this thesis.

However, it was soon realised that the simplified international planning techniques were quite inadequate for the detailed national activities needed for the construction of the network. These demanded much greater precision in field strength forecasting than could be achieved with the internationally-approved method. At the same time, if the plan was to be implemented without objection from neighbouring countries, local changes to prediction methods had to be discussed with them. This saw the start of international activities to develop a computer program capable of achieving the precision required. The BBC took a leading part in this initiative, partly because of arrangements made for the UHF development within the UK, where detailed planning was co-ordinated from 1963 through a joint GPO/BBC/ITA committee. Within this group it was agreed that the BBC should be responsible for the detailed planning - the consensus being that the only thing worse than one planner was two - and consequently their Research Department concentrated upon the development of a new prediction method ^(1.80).

The prediction was developed to use a terrain data base that had been introduced by the power industries for the planning of their own communication networks. The model was based upon ray theory, with parameters defining decay with distance, diffraction losses, and influence of frequency empirically deduced using measurements. The ability to describe terrain along each unique propagation path substantially improved prediction accuracy, and the program was eventually developed to cover all the frequencies used for domestic broadcasting ^(1.81).

Other European broadcasters developed similar prediction programs, and much discussion took place within the technical working parties of the EBU and the CCIR to agree a common approach. However, agreement proved elusive, and indeed the commercialization which took place later in the development of broadcasting and mobile services led to a proliferation in the number and type of prediction programs. Fortunately, during the course of the main development of the VHF/UHF broadcasting services in the UK only the program referenced in the previous paragraph was used, so confusion was kept to a minimum at the national level.

Whilst the coverage planning work was proceeding, further field trials were conducted within the UK to confirm the parameters which were being used, and to consider the question of colour standards ^(1.82). These largely confirmed earlier conclusions, and planning methods remained unchanged. The UHF service opened in April 1964, transmitting a 625-line picture, and the transmitter network rapidly expanded from that date. Simultaneously, work was still continuing on the extension of VHF television, passing through three phases of relay station development. By the early Seventies the BBC VHF 405-line network had expanded to totals of 27 high-power main and 84 low-power relay stations. The independent service, which following the Sound Broadcasting Act of 1972 was now known as the Independent Broadcasting Authority (IBA), contained 21 high-power and 26 low-power installations. Population coverage of the BBC VHF services was approximately 99.5% of the national total, and that of the IBA, 97.8%.

The second half of the sixties had seen the introduction of local radio, partly stimulated by mounting competition from pirate radio stations. Originally conceived as a network of 20 BBC transmitters serving communities in England, a short list of eight stations began to open in 1967. They were intended to operate on VHF only, as assigned in the Stockholm Plan, but failure to attract enough listeners to these frequencies caused the authorities to permit duplication on MF channels. In 1972 the Government authorized the IBA to enter the local scene with a plan for 60 stations, although almost immediately this number was limited to 19 pending the report of yet another committee (chaired by Lord Annan) examining the future of broadcasting ^(1.83).

All these activities placed a great strain on the planning resources of the broadcasters, whose research effort was largely directed to the improvement of their extensive planning computer program. Similarly, the parallel work within the appropriate government departments, now transferred from the PMG to the Ministry of Posts and Telecommunications (MPT), had to concentrate upon the national and international clearance of a mounting number of new transmitting stations. The situation was reflected in other European countries, and international co-ordination of research through the EBU and the ITU was also affected. Yet further distraction to

the specialists in the working parties was created by requests to provide planning information for developing countries who were just introducing broadcasting systems, notably those in the African continent. Different propagation conditions in those areas demanded additional study.

Within the UK, the costs of the UHF television development were escalating. By the early Seventies the service had reached about 94% of the population, but it was obvious that a disproportionate amount of capital was needed to serve the remainder. The objective was to duplicate the VHF television coverage, so that the obsolete 405-line service could be switched off and the frequencies re-allocated, but even if the UHF spectrum contained the assignments needed, and this was doubtful, the costs were daunting. Having virtually completed the main stations, the broadcasters were engaged upon the planning of the relay network. This was to pass through two phases, the first dealing with unserved pockets of population exceeding 1,000 people, the second going down to 500 inhabitants. A total of more than 600 low-power transmitters was needed, leaving about 0.6% of the population still unserved. But whereas the cost-per-head of the coverage of the Crystal Palace transmitter, which served a net population of nearly nine million people, had amounted to a few pennies, the average cost of a Phase II station was about £85 per head, or £250 per household. In order to achieve a realistic time scale for the construction programme, the planners and installation engineers were set a target of 70 stations per annum.

To resolve problems such as those described above, the government sought a further report from the TAC, querying the coverage techniques to be used by the broadcasters after 1976 ^(1.84). Fortunately the BBC representative, the then Director-General, Charles Curran, was very familiar with the problems, and he made a substantial contribution, based upon current BBC ideas ^(1.85). In personal memoirs, he also remarked upon another difficulty, namely the unwillingness of viewers and listeners at that time to invest in new developments, describing the British audience as "the greatest collective connoisseur of the obsolete in the world" ^(1.86). Previously demonstrated by the reluctance to accept VHF radio as a replacement for the deteriorating MF services, the introduction of the UHF service was revealing more examples of this characteristic.

During the same period, the MPT set up a further committee under the chairmanship of Sir Stewart Crawford in May 1973^(1.87). Primarily directed to look at the future disposition of the fourth UHF channel, as yet unallocated by the government, this committee was also asked to investigate the plans of the broadcasters for the eventual coverage of the UK, both television and radio. Their report recommended that the UHF transmitter construction programme should be extended so that the coverage would permit the complete duplication of the VHF 405-line service by the early Eighties. The allocation of the fourth UHF programme should not delay the relay station planning, and the survey work on newly opened stations should be accelerated in order to define the need for new installations (this recognized the fact that the detail of coverage could not be reliably determined by prediction).

With regard to radio broadcasting, the committee concluded there was little hope of improving the LF/MF services, although preparations were being made for a further international broadcasting conference planned for 1975. As an example, night-time MF coverage of Radio 1 in the UK was as low as 33%, due to interference levels. The BBC was encouraged to complete its VHF national network, and both the BBC and the IBA were recommended to extend their local radio services, although duplication should be avoided wherever possible.

The immediate impact upon planning resources within the broadcasting organizations was a substantial increase in the routine activities and a further decrease in research. This was unfortunate, because the need for a more reliable field strength prediction was obvious. Abundant field strength data, both for wanted and interfering signals, was an increasingly vital factor in the choice of transmitting sites, and the specification of each transmitter. The relatively small service area of a relay station was likely to be totally influenced by immediate topography. The direction of incoming interfering signals was important, because the transmitting site could be chosen so that local terrain combined with the directivity of the antennas might be used to minimize the effects. As the network grew, the situation worsened, and in many cases more than one hundred potential sources of interference had to be taken into account in the design of a single small station.

Site finding was also becoming increasingly difficult. "The need for high sites escalated the environmental problems, but again it was noteworthy that complaints usually arose from distant quarters, and not from the locals who would be served by the proposed transmitter. To some extent these problems were reduced by site sharing with other services, such as the police, fire and ambulance, although these facilities often aggravated the physical appearance of the mast. Often they also demanded detailed discussions concerning the technical specifications for each installation. Several examples can be identified where years were to elapse before particularly sensitive sites could be cleared for use, following the examination of many alternatives and public enquiries. The worst case on record (in the Bristol Channel area and already mentioned earlier as a problem during VHF planning), took seven years. The optimum site was on the Mendips, because this substantially reduced the number of relay stations required. But the environmental problems created by a large, prominent mast in such a location demanded that all possible alternatives had to be fully explored.

Hard on the heels of the Crawford report came that of the Annan Committee^(1.83). They had been asked by the government to look into the future of broadcasting, and perhaps the most memorable features of their report are those which received the greatest criticism from the broadcasters. The first, from the BBC, because the committee wished to restrain the growth of their local radio service, and the second from the IBA, because of the proposal to give the fourth UHF channel to a new company - the Open Broadcasting Authority. However, the Home Secretary, William Whitelaw, disagreed with the latter, and awarded the new channel to the IBA. Already included in the ongoing UHF plan, this caused relatively minor planning problems, although it became clear that the actual channel allocation available in each area often provided the worst coverage of the four (usually higher interference levels) because the channels already in use had been selected for optimum performance.

So the beginning of the Eighties witnessed a substantial improvement in the prospects for independent broadcasting. In contrast, the BBC was passing through a lean time, as described by

their Controller, Future Policy Group ^(1.88). The need to propel the UHF project meant other projects had to be abandoned and one example, which at the time was seen to be fully in keeping with the ethos of public service broadcasting, should be mentioned. This was a proposal known as "CARFAX", which was very attractive in engineering terms because it offered a complete solution to the problems of providing a dedicated traffic information service to the road users for the allocation of a single MF channel. At the time it could have been put into operation very economically, and would have saved millions of pounds in transport costs. Its advantages have yet to be equalled by modern systems. However, the proposal was eventually abandoned for a somewhat superficial technical reason; in reality the government was unwilling to offer the frequency assignment needed ^(1.89).

During the Eighties the construction programme of UHF relay stations continued at the planned rate of about 70 new sites per annum. Early in the decade the theoretical coverage exceeded 99.5% of the population, and by that time nearly 1,000 stations, each transmitting four programmes, were in operation. To establish the comparative coverages of VHF and UHF services extensive tests were carried out by the broadcasting authorities and the government department which had now assumed responsibility for broadcasting - the Radiocommunications Agency of the Department of Trade and Industry (DTI). In 1983 the DTI set up an independent review of the radio spectrum from 30 - 960 MHz, and this recommended closure of the VHF 405-line services ^(1.90). Subsequently this same committee recommended that the spectrum space freed by this action should be assigned to the growing mobile radio industry, and the DTI presented a consultative document to the government shortly afterwards ^(1.91). The 405-line service was finally closed down in January 1985.

1.9. The Growth of Satellite and Cable Services

The re-distribution of sound signals over various forms of cable in areas where off-air reception was inadequate goes back to the beginning of broadcasting, and the technique was eventually

developed for television distribution. In 1950 the PMG announced that he would consider applications for licences for commercial cable systems, and by 1951 four such schemes were in operation. These were “narrowband” systems, capable of carrying television and perhaps one or two sound channels. Many others were to follow, and for a period in the early Eighties about 10% of the population of the UK opted for this form of reception. The proportion fell later as the BBC and IBA off-air network grew, until by 1985 the total number of homes connected had dropped to about 130,000, about 16% of those actually “passed by” the systems. The term “passed by” means connection is available at the house, and illustrates one inherent disadvantage of the technique, whereby a company has to invest a considerable amount of money to bring cables to the area, although relatively few occupants may require connection. The cost of cable is notionally higher than that needed for a terrestrial off-air network (very much so in rural areas), although the equation moves in favour of the former when its potential to provide many channels and “interactive” (signals from the home) is taken into account.

Advances in cable technology, notably the development of coaxial and fibre optic cables led to “broadband” systems, with the capacity to carry several television and sound channels, together with text and data signals. The government was keen to develop this form of transmission, and new regulatory machinery defined in the Cable and Broadcasting Act of 1984 followed a White Paper, which led to the formation of the Cable Authority ^(1.92). This new authority was not dismayed by the downturn in 1985, it was anticipating a substantial increase in the demand for cable with the advent of broadband systems and satellite broadcasting, forecasting between 3.2 and 5.1 million subscribers by the year 2000, with a “homes passed” proportion equalling 41% of the UK total households ^(1.93). This latter compared with the figure of 76% in the United States, where cabling thrived in the dense urban communities.

To ensure interference was not caused by cable systems to existing off-air reception, liaison was maintained from the earliest days between the broadcasters and the Relay Services Association of Great Britain ^(1.94). However, until the mid-eighties, cable systems were never officially taken into

account by the broadcasters or the government when off-air coverage was being planned, although most of the many committees who considered the future of the media mentioned their existence. Most cable systems were initiated and operated by commercial companies, and it was considered that it was advisable in preparing a national coverage plan to exclude the potentially uncertain contributions that these systems were making. This was unfortunate, because if the option had been available a much more efficient overall terrestrial broadcasting plan could have been produced.

Satellite transmission presented a totally different prospect. If technically achievable, it offered virtually nationwide coverage from a single transmitting source. Theoretically, the thousands of terrestrial transmitters could become obsolescent, and the only immediate objection apart from the obvious problem of cost was the apparent inability to supply local areas with their own material - such a transmitter out in space would cover a substantial proportion of the earth's surface.

The early experiments with Telstar were followed by the launch of Syncom and Early Bird into their geostationary orbits in 1963 and 1965^(1.95, 1.96). Development over the next ten years of all the components needed to achieve a reliable satellite service led to the World Administrative Radio Conference of 1977, which agreed a Direct Broadcasting Satellite (DBS) plan occupying the frequency band from 11.7 to 12.5 GHz. By 1988, 18 satellite-delivered channels were broadcasting across Europe mainly from three low-powered satellites serving cable headends - satellite master antenna television (SMATV) systems which fed hotels, apartment blocks and small community groups. These low-powered transmitters required large receiving dishes, and competition to increase the power of the satellite transmitters began. Plans were produced in Europe for a medium-power source - Astra - intended to transmit eight English channels, but the UK was also proceeding with proposals for higher power. Originally the Government envisaged that the BBC and the IBA might provide separate competing DBS services, but in view of the costs a co-operative venture was agreed. Provision was made in the Cable and Broadcasting Act of 1984^(1.92), but in June 1985 a shadow consortium decided not to proceed with this arrangement. The

government invited the IBA in 1986 to organize three DBS channels through a separate statutory route, and British Satellite Broadcasting (BSB) was the result. Simultaneously the government extended the licensing of the low-power SMATV systems, recognizing the potential growth in this area.

The government also examined the possibilities of providing further off-air terrestrial programmes, using certain channels in the existing UHF broadcasting bands, and a technique already adopted in the USA - multipoint video distribution systems (MVDS) - which operated at microwave frequencies^(1.92, 1.97). The UHF study led to a decision to implement a limited service - Channel 5 - which it was hoped would reach about 60 to 70% of the population of the UK, using some of the existing UHF transmitting sites.

Thus the broadcasting situation at the end of the 1980's was effectively defined by the White Paper published in 1988^(1.92). There were to be five UHF terrestrial channels (a sixth was suggested but proved to be impracticable), a "flexible" regime for the development of cable and MVDS outlets, and three national DBS channels, with two more to be added. Other satellite services, such as the Astra and Eutelsat II transmissions, would be receivable in the UK. Several administrative changes were proposed - the BBC to continue but with revised financial arrangements, the formation of the Independent Television Commission (ITC) to replace the IBA, a Broadcasting Standards Council (BSC) to purvey programme standards, the deregulation of independent radio, and a major reform of all the transmission arrangements - "giving scope for greater private sector involvement". In essence this last objective meant transferring the Transmitter Department of the BBC into private hands (Castle Transmission International), and the formation of National Transcommunications Limited (NTL) from the engineering operations of the IBA.

1.10. The Situation at the End of the Twentieth Century

The Eighties witnessed the start of a revolution in broadcasting, and indeed in the whole area of home entertainment and communication, that was to accelerate in the Nineties. By the end of the

century, of the 24 million homes in the UK, more than 98% had television, 60% of these had more than one receiver, and 32% had multi-channel services delivered by satellite or cable. More than 85% had a video cassette recorder (VCR) and 73% had teletext. Nearly one-half of homes had a personal computer, and well over that proportion of the population had a mobile telephone. This phenomenal expansion was the result of two factors.

Firstly, technological development, notably in electronics, opened up many new possibilities. Largely attributed to the massive growth in computer memory and signal processing power, virtually every aspect of the electronics industry was affected. Gordon Moore of the Intel Corporation noted in the early Nineties that the processing capability and the amount of semiconductor memory on a silicon chip doubled approximately every 19 months. This empirical relationship held since the early days of integrated circuits and he anticipated that it would continue for the next twenty years. Time-shifting facilities offered by the VCR and its disc successors transformed viewing habits, and when compared with off-air reception, revealed the potential for studio-quality reproduction. The scope for the convergence of the two forms of visual display in the home - the personal computer and the television receiver - was recognized.

Secondly, the legislative procedures that had previously regulated some of the services were lightened in the last decade of the century; hints of this were contained in the 1988 White Paper, which included the concept of selling spectrum to the highest bidder ^(1.92, 1.93). This change in attitude can be attributed to the government "market forces" philosophies established in the Eighties, although it might also be concluded that the authorities were overwhelmed by the consequences of the technological explosion. Whatever the reason, the new "laid-back" attitude of government contrasted with that adopted in the past, when official enquiries into the future of broadcasting and strategy statements were continuous performances. The new attitude was particularly obvious in the phenomenally rapid introduction of the mobile telephone, a service that reached near-national population coverage in a few years, encouraged by ready access to freed spectrum space and eased planning restrictions. This particular development illustrates one very significant difference from the rigorous planning approach which had to be used by broadcasters,

mentioned earlier in this chapter. Whereas broadcasting was primarily intended for fixed receivers, and adopted a transmission system using high masts and high powers, the mobile service involved a dense network of low mast, low-power, inexpensive installations. These required minimal planning negotiation, and it proved to be a flexible system. If a base station performs poorly, then the equipment can be readily modified or even re-sited, and the mobile users will rapidly adjust to the new conditions, often unaware of any change. Of course, the limitations of size imposed by the demand for mobility means that it cannot yet offer the developments of scale in the plasma and liquid crystal displays available in the home, but it has rapidly become a major component in the interactive entertainment/communication scene.

The lack of long-term strategy was again obvious when the decision was taken to move from analogue to digital modulation for broadcast transmission. Within Europe, most countries participated in the digital conversion discussions, which began in the late Eighties ^(1.98), although authorization by the UK Government to introduce such a service was not given until 1996. Various reasons can be put forward in favour of digital transmission – more channels, improvements in quality, cost-effectiveness – but at the time the long-term implications were totally unclear and this no doubt contributed to the official indecision. There is no doubt that the possibilities of duplicating the existing terrestrial coverage was not explored in the sort of detail that was used when the VHF/UHF changeover took place. The whole process might have been immensely simplified, for example by a decision at the outset that the terrestrial channels would not undergo digital conversion, that the ultimate objectives could be achieved by a mixture of satellite and cable transmission leaving the terrestrial services to be “re-engineered” as their audiences diminished. Such a solution involving migration to a new frequency band by just two broadcasting organizations was possible when the 625-line UHF service took over from VHF, but the situation in the Nineties was commercially and technologically much more complicated. Nevertheless, having regard to subsequent developments, more independent research would have been immensely valuable at the time.

Certainly, having taken the decision, those involved in the broadcasting and associated industries could not adopt a "wait and see" policy; the future looked bright. To ensure as far as possible that the right technical strategy was chosen, the period witnessed a vast increase in the number of national and international specialist committees devoted to the incredibly complex task of agreeing technical standards for the new services ^(1.99, 1.100.). As the possibilities were discussed, the already complicated challenge of analogue/digital conversion was made more difficult by ambitious proposals to consider factors such as high definition (HDTV), changes in picture aspect ratio, and subscription facilities, and the number of professionals involved in the subject multiplied. Inevitably, the service planning engineers, anxious to examine the spectrum demand and confirm the basic feasibility, had to set aside much detail in order to pursue the main objective

Virtually from the outset of the digital project it was recognized that the costs and problems of converting the existing terrestrial, satellite and cable systems were going to be considerable. In order to capitalize on their existing near-national coverage, the terrestrial services attempted to achieve an analogue/digital conversion as quickly as possible using the existing transmitter sites, thereby maintaining both an audience and an income. However, the problems of introducing many new interference-free services in the same spectrum as that already used by several existing networks had not been experienced on such a wide scale before. Several European countries deferred a decision whether or not to proceed, but this could not delay the need to define technical parameters that would achieve a plan ultimately suitable for all. By 1996 the EBU had agreed a scheme for planning ^(1.101, 1.102), and negotiating machinery was established whereby DTT, or digital video broadcasting (DVB), networks could be extended across Europe alongside the existing 7.0 and 8.0 MHz analogue assignments. Apart from specifying system variants and modulation techniques, the project had to agree planning parameters, including those dealing with the all-important field strength prediction. Under pressure, the engineers had to fall back on the universally-accepted techniques, and in this thesis it will be argued that these contain significant defects. Thus it is postulated that the all-important frequency plans for the new terrestrial services, intended to carry the telemedia services forward into the twenty-first century, will continue to use a

field strength prediction which has been inadequately researched, similar in many vital respects to one which was developed for use at a planning conference more than 40 years ago.

More detail concerning the coverage prospects during the early years of the digital project are given in Chapter 5, but certainly the last decade of the twentieth century was one of confusion for the public. Suddenly they were confronted with a "telemedia" explosion - a "fifth dimension"^(1.103, 1.104). The terrestrial network, which for more than 50 years had provided stable services to the majority, was under notice. A fifth terrestrial network was opened, but this was only achieved with difficulty, required the re-tuning of many hundreds of thousands of VCR's in order to free a few channels, and left a third of the public unserved. The far more complex process of converting the existing analogue UHF service to digital transmission was started, but its advantages as far as most people were concerned were completely obscure. Vague official pronouncements offered some comfort - before the analogue service is switched off, "95% of those receiving the "main public service broadcasting channels" in analogue *should* be able to receive them digitally. But disturbingly the public was left to sort out what it wanted, in the face of a mass of advice and jargon that even many professionals could not understand, and with no assurance regarding the long-term use of some of the equipment flooding the market. Small wonder that a substantial proportion of existing viewers were initially disinclined to abandon their analogue reception. The propensity noted by Charles Curran still existed, but was now aggravated by near-total uncertainty. Thus, about 50 years after the national VHF/UHF terrestrial services were introduced in the UK, their nationwide audiences were advised that although they had been well-served, closure was definite. However, improvements now made possible by new technology were coming.

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2. Service Planning Since 1945 - The International Scene

2.1. Summary

The massive growth of the terrestrial transmitting networks after the 1939/45 War transformed the scale of the problems confronting those concerned with planning broadcast services, and this marks the real start of the design of the complex system which now exists. There was a demand for all sorts of technical data, particularly that concerning radio propagation. The immediate requirement was for techniques which were:-

- internationally agreed
- capable of providing field strength predictions of sufficient accuracy for the preliminary planning of transmitter networks, allowing the specification of the approximate location of each transmitter, its frequencies, powers, antenna heights and so on
- easy to understand and use, having regard to the unique demands of large, multilingual international planning conferences
- as far as possible free of any need for complicated supplementary information, e.g., terrain or tropospheric data.

Following the technical description of coverage, this chapter deals with the first intangible assessment that confronts the planning engineer, namely the equation of qualitative reception standards and quantitative field strength values that determines whether or not the user will regard his reception as adequate. A field strength prediction method devised primarily to deal with the planning of international high-power networks is then described. However, although based upon an enormous number of measurements, inability to define precisely what these results represented,

and consequent obfuscation of the meaning of the prediction, caused its value to be questioned. Nevertheless, the method has remained in use internationally because a better alternative could not be agreed. This Chapter concludes with a preliminary critique of the prediction.

One important factor must be underlined before embarking upon detail. Emphasis has been placed throughout this project on the accuracy of field strength determination, the impact this precision has upon the assessment of service quality, upon planning decisions, the deployment and expenditure of resources. In the course of planning, particularly in international negotiations, it is often necessary to distinguish quickly between the pros and cons of alternatives. In these circumstances the accuracy of an individual calculation may be regarded as less important than the tendency revealed by the comparison of successive assessments. Absolute precision would be ideal, and the implications of failure to achieve this are examined later, but there have been many occasions when planning decisions have been made following the simple comparisons of trends.

2.2. The Definition of Coverage

“Coverage” is associated with an area, either achieved by a single transmitter or a complete network, and the basic definition is given in an ITU Recommendation ^(2.1):-

“The area within which the field-strength of a transmitter is equal to or greater than the *usable field strength*.

In the case of fluctuating interference or noise, the percentage of time during which this condition is satisfied should be stated.

The coverage area may be different under day-time and night-time conditions or vary with other factors.”

The term “*usable field strength*” is further defined in the same Recommendation:-

“.....the field strength necessary to permit a desired reception quality, under specified

receiving conditions, in the presence of natural and man-made noise and interference, either in an existing situation or as determined by agreement or frequency plans."

To plan coverage it is necessary to establish standards for the performance of the terminating equipment, for example, to define the ability of the receiver and its antenna to select the wanted signal and reject noise and other interference. The field strength levels of the wanted and unwanted signals must be measured or predicted, and the protection ratios which must exist between them in order to render interference imperceptible have to be specified. However, a broadcast service is a "point-to-area" system, distinct from "point-to-point" networks where the link is between points fixed in space for the terminating antennas. The broadcast transmitting antenna occupies a precise point, but listeners or viewers may wish to use the service at any position within its nominal coverage area (and often beyond it). Thus the measurement/prediction process is more complex than the point-to-point situation, because it has to estimate the spatial variations which will occur throughout the service area, even though it is only practicable to measure or predict results at relatively few sample locations.

In determining the field strengths, particularly those of unwanted signals which may be coming from very distant transmitters, the variation of their levels over time must also be forecast. The fluctuations may be due to a variety of causes, but the nature of these changes and the electrical combination of the individual contributions at the receiver will affect the characteristics of any interference.

Thus "coverage" is essentially the outcome of an analysis in which the levels of the wanted signal are compared with those of any unwanted transmissions. Conveniently, it is quantified in terms of field strength to produce a statement that x% of the receiving locations will receive an adequate service for y% of the time.

In the early stages of development, before computer techniques became widely available, the assessment of service ranges depended largely upon measurement, and interference calculations

were very approximate. Computers have allowed more thorough analysis, and in modern, dense UHF networks, the analysis of the range of the *wanted* signal of a single new medium-powered transmitter often requires several hundred, even thousands, individual measurements or predictions. Some of these are then selected, and a separate assessment is carried out for each requiring field strength predictions from perhaps one hundred other existing and planned stations which are potential sources of interference. Similarly, the interference potential of the new station upon the service areas of these other installations has to be investigated. During the years of development the situation remains dynamic, with theoretical interference levels changing as new stations are added, and new information arriving concerning the existing coverage. In the later stages of the UHF network development, a single appraisal of the state of the overall UK coverage plan involved calculations for more than four million propagation paths. It was common practice to carry out such an analysis at quarterly intervals.

Before describing the development of coverage prediction, it is necessary to review the factors that have decided the standards required for adequate reception, because the subjective appraisal of the quality at that point is the real measure of success. To contain the size of the discussion, the focus here is upon television reception, although where necessary radio conditions are also mentioned. A fundamental difference between the two is that for the great majority of users, television is viewed at fixed locations, and requires population coverage, i.e., the service is designed to reach people in their homes. With radio, the existence of a substantial proportion of mobile users has to be taken into account, and area coverage is an additional requirement. However, with the growth of television reception in road vehicles and trains, this distinction is diminishing.

2.3. Reception Standards - The "Minimum Field Strength"

The factors defining the voltage needed at the input to a television receiver in order to overcome internal and external noise were summarized in a paper produced in 1959^(2.2). It dealt with 405-line television transmission, with an energy bandwidth of 2.75 MHz, and was the basis upon which much of the planning for that VHF network proceeded in the Forties and Fifties. The minimum

signal/noise ratio is that value at which the noise just begins to degrade the picture, and subsequently tests were conducted to confirm both this value, and the relationships between quality and field strength. Included amongst these was the early evidence which was contributed to the ITU in 1956^(2.3), and results from the television trials already mentioned in Chapter 1^(1.69, 1.70). General comment on all of these is made by considering the comparatively recent example shown in Figure 1, which relates to reception of a UHF colour transmission (623.25 MHz), and demonstrates the percentage of viewers classifying the quality of their reception as Grade 3 (Fair), Grade 4 (Good) or Grade 5 (Excellent), as a function of the field strength of their signal^(2.4).

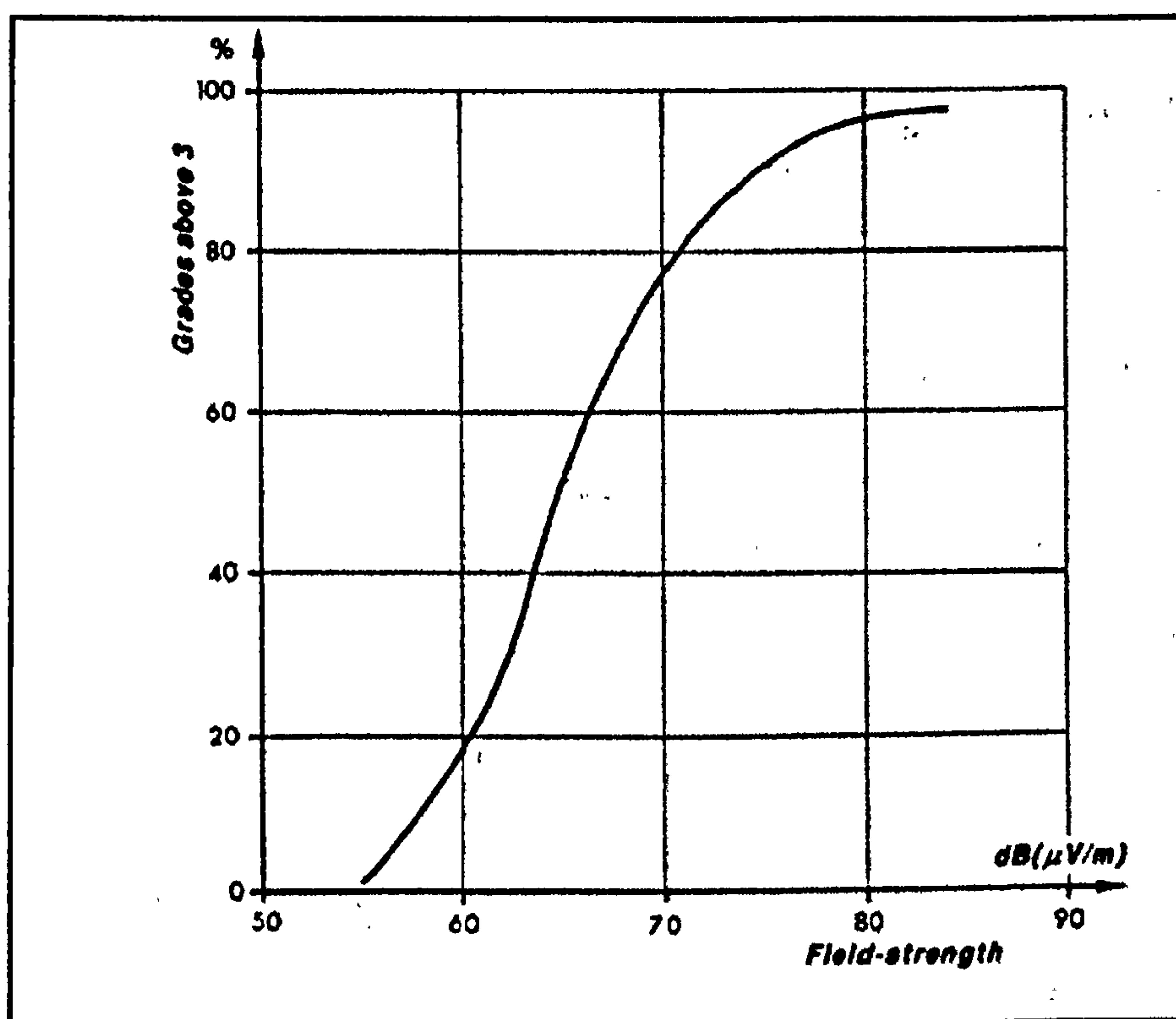


FIGURE 1
PICTURE QUALITY ASSESSMENT

Percentage of viewers grading their reception as Grade 3 (Fair) or better, as a function of field strength

These subjective results were obtained using observers working in broadcasting, some of whom were specialists in picture quality. They were highly critical, and it might be assumed that the standards proposed would be high compared with those demanded by the general viewer. In fact, recent investigations by the author into viewer reactions produced similar results at the high end of

the field strength range, although there were significant differences for lower values, when affected by interference (see below).

The very early assessments were conducted under laboratory conditions. Virtual closed-circuit television (CCTV) conditions were employed, the "propagation path" being simulated by an adjustable signal to noise ratio. Subsequent tests, using mobile laboratories and home receivers generally within the service range of test transmitters produced similar evidence. Additional laboratory studies, using locally-generated signals, were carried out to determine impairment caused by interference, and results were obtained which were virtually identical to those produced from the quality tests. The early conclusion was that perception of this type of interference was broadly similar to that observed for noise, and the same curve was adopted for the assessment of both quality and impairment. However, as mentioned above, recent work suggests that the particular patterning caused by co-channel interference (CCI) is more disturbing than noise, often resulting in subjective rejection of reception at much higher levels than those shown in Figure 1.

The idealised curve of the type shown above formed the basis for the specification of minimum field strengths to be provided by the broadcasters. To link this value to the field measurement work, it was assumed that an external receiving antenna at 10 m. a.g.l. would be used for television reception, a figure representing the average height of a domestic antenna mounted at roof level on a two-storeyed house. In the case of the VHF/UHF services, the antennas were assumed to have specific gain and a directivity capable of reducing interference from sources outside certain beam widths. In practice, of course, domestic antennas are mounted in a variety of locations on and in the home, and tests were conducted to relate results obtained in alternative positions to those measured at the datum of 10 m. a.g.l. in the road, one of which is referenced here ^(2.5). This experimental evidence was combined and the quality of service which should be achieved by stated percentages of the viewers was estimated. As an example, Table 1 forecasts the percentages of satisfied viewers using the UHF services, i.e., those receiving pictures graded 3 or better, for stated values of field strength measured in the road outside their homes.

Field Strength (dBuV/m) at 10 m. a.g.l. in road	Antenna Location - % Satisfied Viewers			
	Roof	Loft	First Floor	Ground Floor
90	97	95	94	79
80	94	79	69	18
70	73	18	7	n.a.
60	13	n.a.	n.a.	n.a.

TABLE 1
RECEPTION ASSESSMENT (UHF TV)

**External field strengths compared with percentages of viewers
grading their reception as Grade 3 or better, using the
locations specified for their receiving antennas**

For planning purposes, it was assumed that the viewers would do their best to obtain reasonable reception, and this would require an external, directional antenna mounted not less than 10 m. a.g.l. In the case of the UHF television network, an absolute minimum of 65 dB μ V/m for individual reception was adopted; at this level about 50% of viewers with roof antennas were expected to get adequate reception. A median value of 70 dB μ V/m was regarded as the limiting value for the service area contour, i.e., along this line 50% of the receiving locations would receive at least this value of field strength. The development of the reception standards for the VHF frequency-modulated radio services is not reported here, but a minimum field strength of 48 dB μ V/m was initially chosen. Later the situation was complicated by the need to make distinctions between static and mobile (notably in-car) reception, and provide for stereophonic services.

Now, with the benefit of more than forty years of operational experience, three important observations can be made concerning the original minimum field strength values adopted for the television services. These observations are developed later, but they are introduced here.

Firstly, the early tests concentrated upon the presence of noise, and the future conditions in which a hundred transmitters might have to share the same frequency channel could not be foreseen. Interference proved to be a factor which limited the coverage of much of the UHF service, and the effect upon the quality curve has already been mentioned. In an appraisal made by the author of the overall interference situation throughout the near-complete UK network in 1996, 78% of the

test receiving locations included in the computer prediction revealed theoretical interference levels in excess of the minimum field strength levels. This does not mean, of course, that this proportion of the coverage was affected, because theoretically the level of wanted field strength exceeded the predicted level of interference in most cases, but it does emphasize the significance of this feature as the factor limiting the service.

Secondly, the field strength standards depend upon the statistics which were used to describe changes in the location of the receiving antenna. Many tests were conducted to relate the value of field strength at the domestic antenna to that which could be measured in the adjacent road, but of course, measurements or predictions could not be made outside every potential receiving location. The means of quantifying the "local variation factor" at the time did not reveal the likely distribution of field strength in the vicinity of the sample measurement. Furthermore, differences in this factor between wanted and unwanted transmissions remained unresolved.

Thirdly, a flaw existed in the link between measured field strength and the quality of service . If the receiving antenna is non-directional, i.e., it accepts without attenuation not only the direct signal but also reflections arriving from other directions, then the reception may suffer from multipath interference. Thus the use of a non-directional antenna during measurement may produce a misleading result, field strength may be high but reception quality poor. In the absence of some means of assessing the quality of the reception, field strength alone is not always a reliable guide. Described later, this feature primarily affected the assessments of the VHF services.

However, it was reasonable to assume in the early days that field strength values would be sufficient to forecast the theoretical extent of coverage, and would provide the information needed to specify the transmitter requirements. The need for reliable prediction was obvious, and the international activity in this area that provided the basis for all further work is now described.

2.4. Coverage Prediction - The International Initiative

2.4.1. The Background

As described in the first Chapter, the basis of an international field strength prediction method suitable for the VHF services was established in the late Forties when the Atlantic City conference defined the frequency bands, and various propagation experiments were set up. These provided data for the first European assignment plan agreed in 1952, and over the next nine years this method was developed for use at the 1961 VHF/UHF Conference held in Stockholm. The basic prediction details were transferred two years later into CCIR Recommendation 370^(1.79), which was to remain substantially unchanged throughout its subsequent history. For this reason, the origins of this prediction, and the measurements upon which it is based, have been of fundamental interest in this research into the terrestrial networks. There are also other associated CCIR Recommendations and Reports dealing with propagation and the reception quality of television and radio broadcasting, to which reference is made at points in the following text.

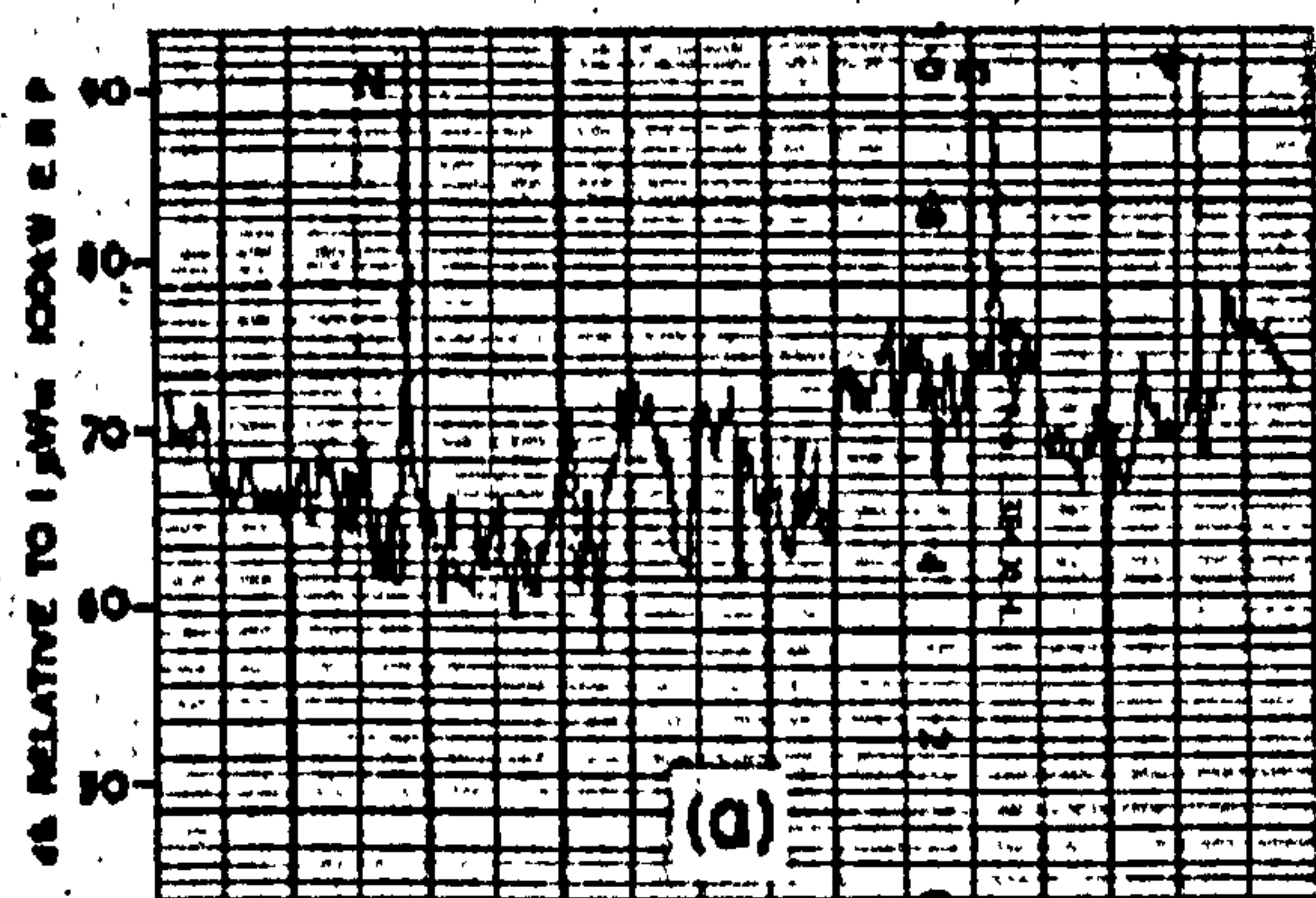
The propagation curves which form the bulk of Recommendation 370 demonstrate the decay of field strength as a function of distance from the transmitter over a range of 10 to 1000 km. Their prime value is to give guidance in "the determination of the minimum geographical distance of separation (of co-channelled transmitters) required to avoid intolerable interference due to long-distance tropospheric transmission...."; they are of relatively little value at short ranges for the prediction of service area field strengths, although on many occasions they have had to be used for this purpose as well. They are based on many thousands of observations and measurements provided by several countries, and because the value of the whole prediction depends upon these individual contributions, their content has been examined in detail. The results of this examination, which concentrated on the UK data, are now described. The description is sub-divided, dealing firstly with short-range results - path lengths within about 100 km - and secondly with measurements made at longer ranges.

2.4.2. Short-Range Results

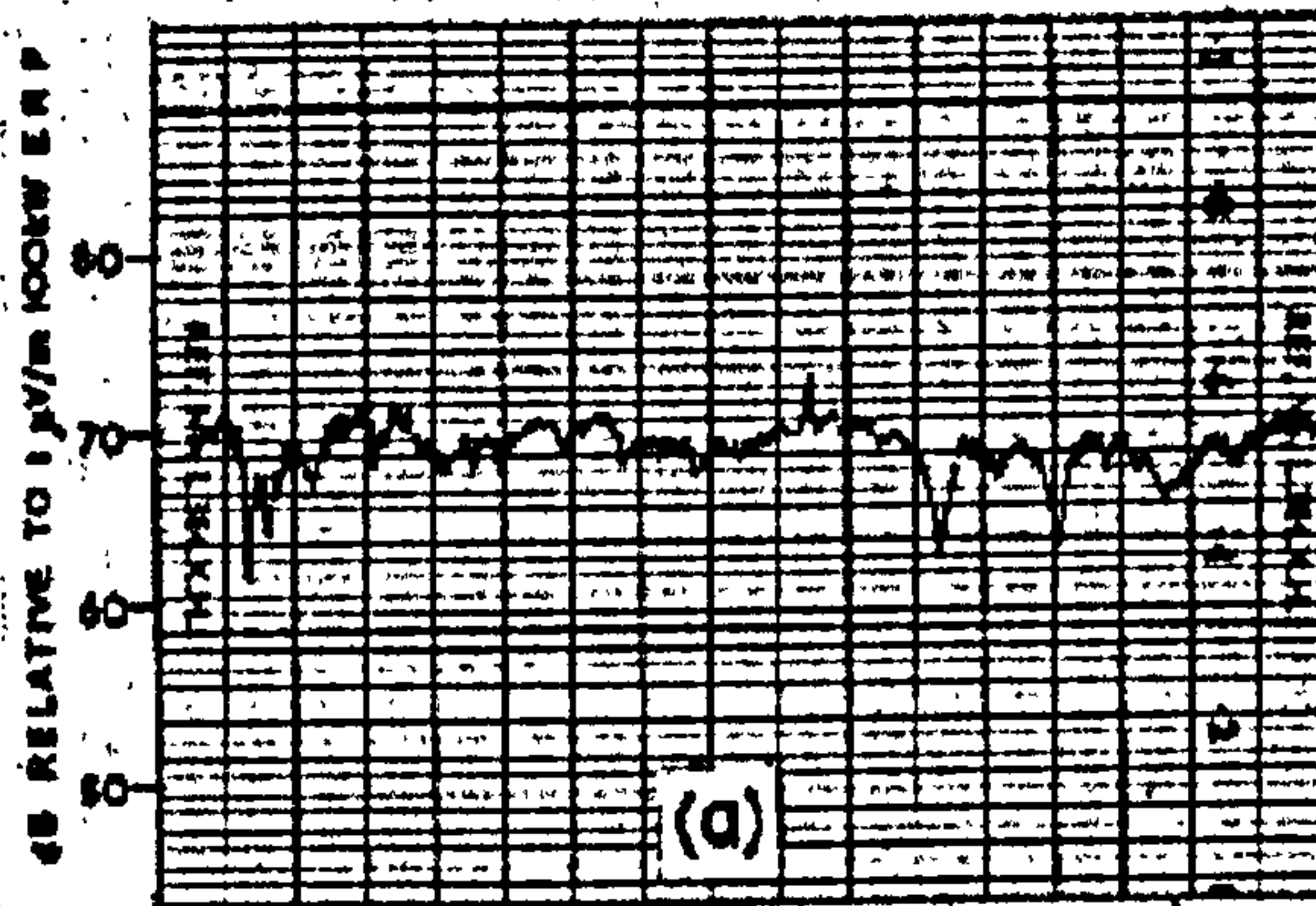
Measurements for the shorter ranges came almost exclusively from the rapidly expanding number of routine site tests and surveys conducted to plan the operational characteristics of new television transmitters. In the absence of an acceptable model for the detailed prediction of field strength over irregular ground, measurement was the only practicable solution for the short-range investigations that were primarily concerned with spatial changes in field strength. The nature of the measurement techniques is important to an appreciation of subsequent analysis, and the methods adopted in the UK provide typical examples.

The first technique, employed for the early VHF radio and television stations, used a non-directional receiving antenna mounted at some convenient height upon the measuring vehicle, the received signal being chart recorded whilst the vehicle was in motion. The output was corrected by the addition of a linear height gain to give the field strength assumed to exist at the internationally accepted standard height of 10 m. a.g.l. (for the earliest results in the UK the Imperial scale of length was used, and the figure was 30 ft. a.g.l.)^(2.6). A survey of a high-power station would result in an average of about 3000 km of road measurement, although some of the larger stations required three or four times this amount. A variant of this technique, adopted for UHF measurement, employed a directional antenna oriented towards the transmitter using a gyroscopic compass, corrections being made for height gain for only those sections of the recorder chart where the foreground towards the transmitter was open. In these circumstances the application of a linear height gain correction was shown to be reasonably accurate.

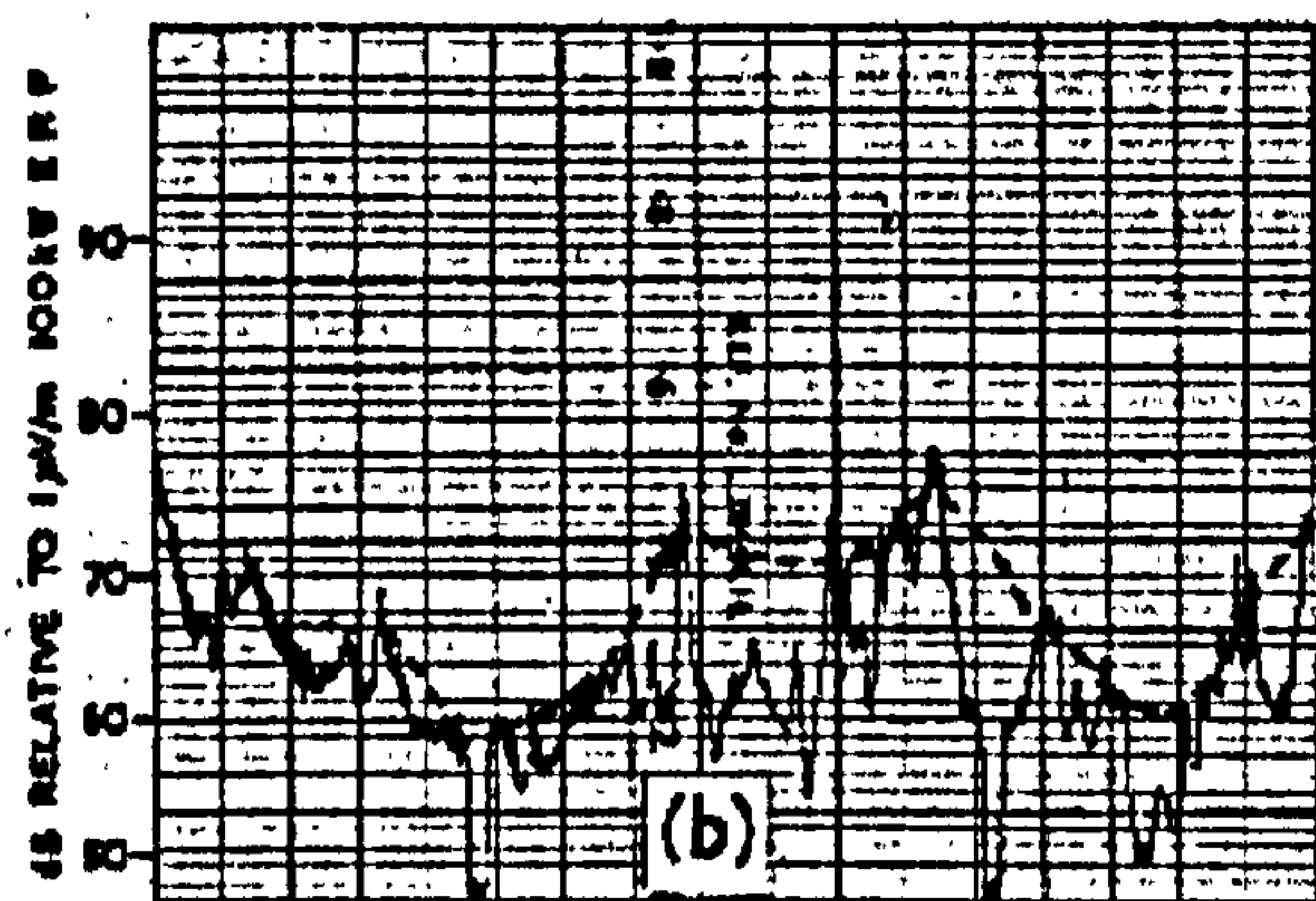
Figure 2^(2.7) shows examples of continuous measurements made over the same two lengths of road, using three frequencies, the first in the VHF band and the second and third in the UHF bands. The first and second were made using non-directional receiving antennas, whilst the last employed a directional unit. It can be seen that there is some increased scatter of the signal, caused by the shadows cast by buildings, but only the directional antenna reveals the real loss, because the others



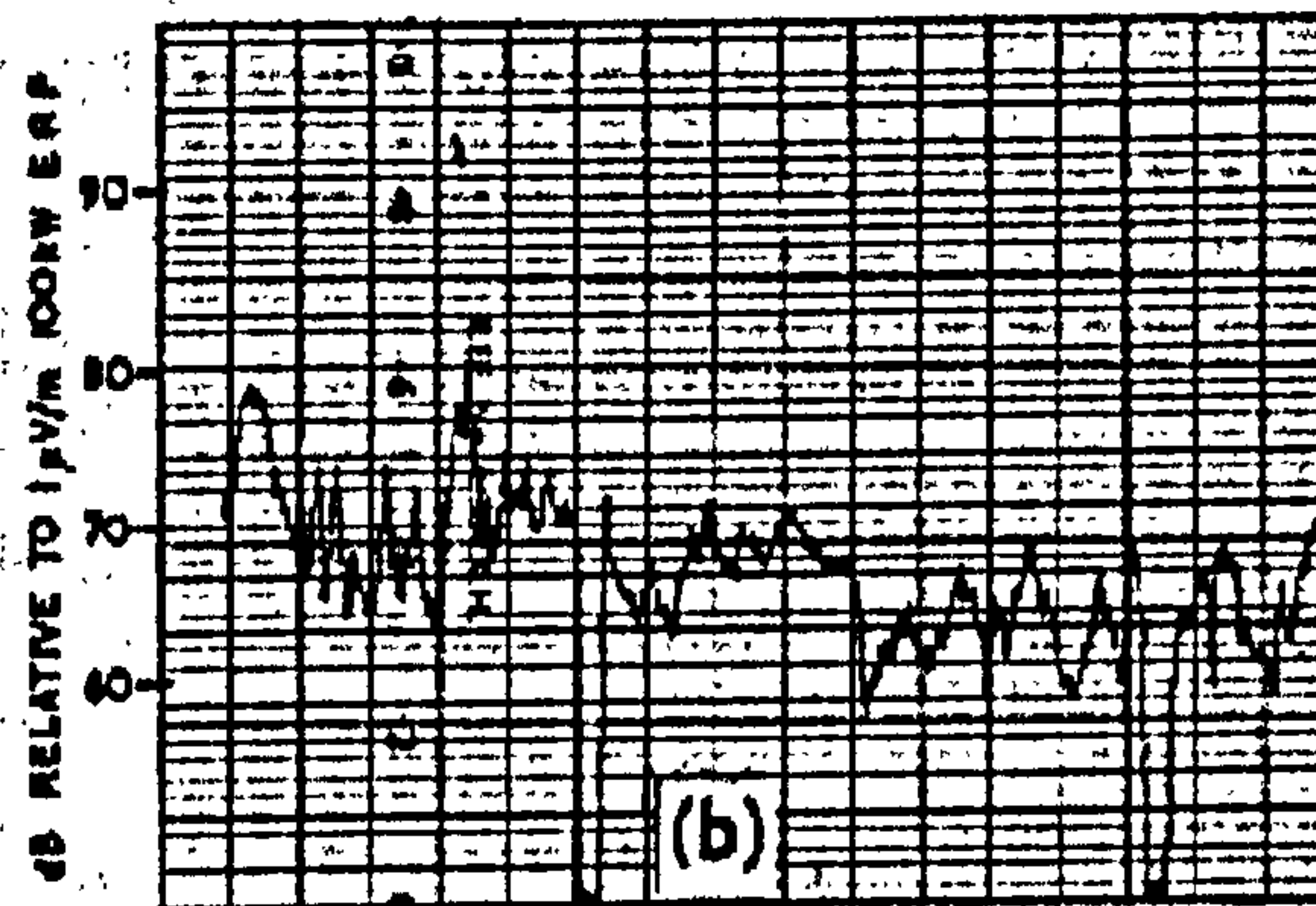
WESTERHAM, BAND I J AERIAL 15ft (4.6m) AGL



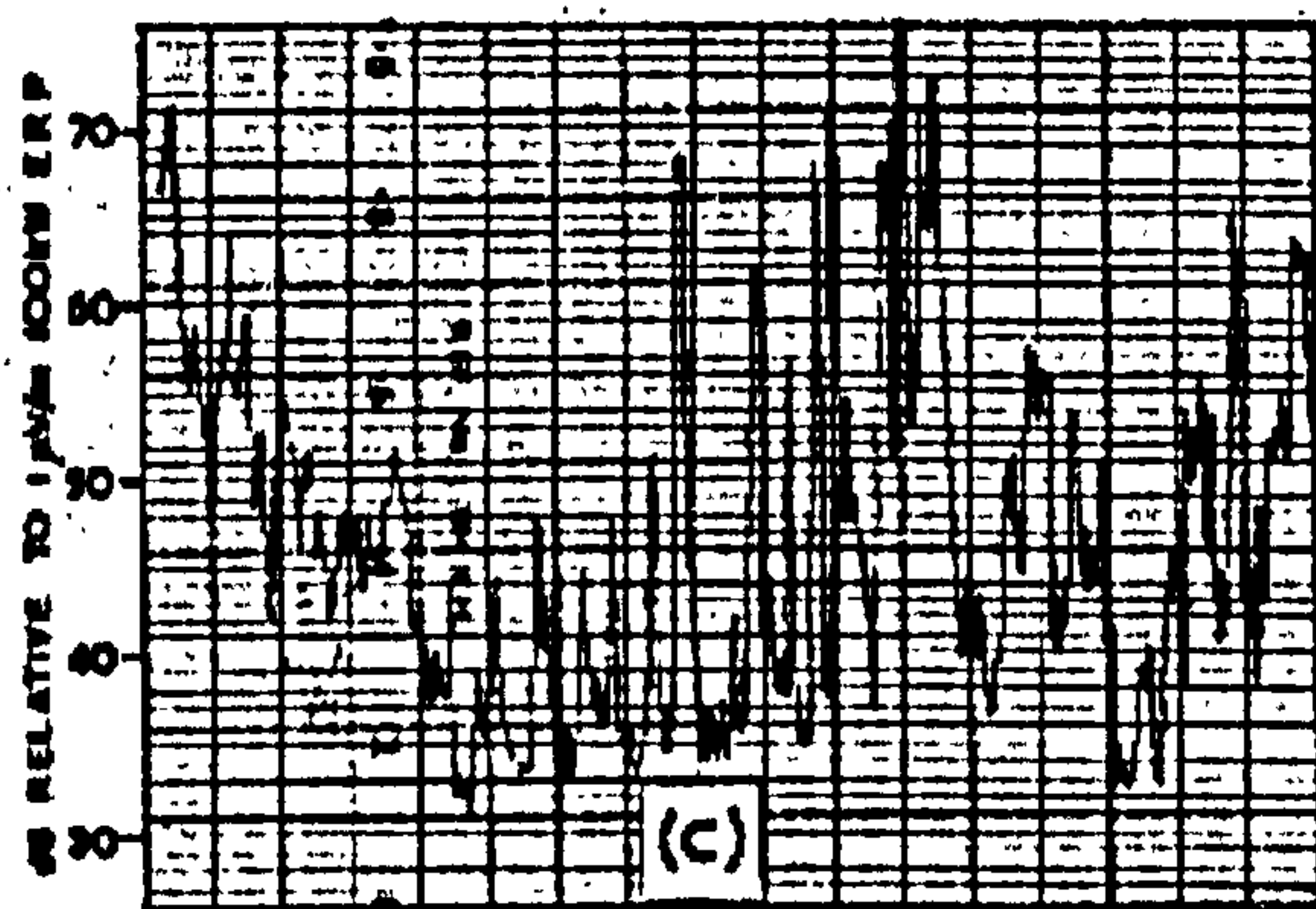
TREE-LINED ROAD, BAND I J AERIAL 15ft (4.6m) AGL



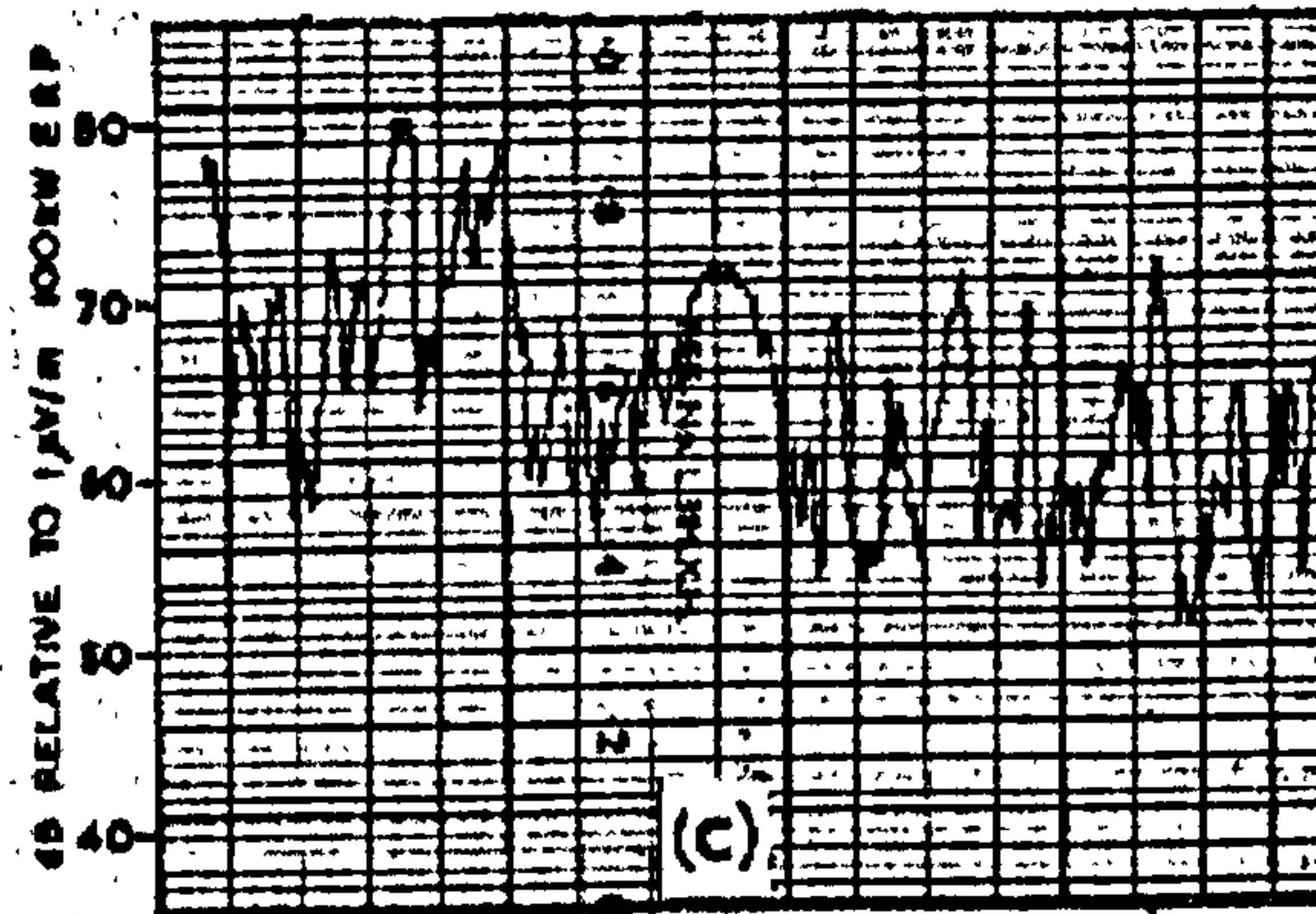
WESTERHAM, BAND IV BATWING 12ft (3.7m) AGL



TREE-LINED ROAD, BAND IV BATWING 12ft (3.7m) AGL



WESTERHAM, BAND Y YAGI 12ft (3.7m) AGL



TREE-LINED ROAD, BAND Y YAGI 12ft (3.7m) AGL

FIGURE 2
EXAMPLES OF CONTINUOUS MEASUREMENTS

Field strength measurements made over two identical road sections
 Recorder charts (a) Frequency 41.5 MHz using non-directional receiving antenna
 Recorder charts (b) Frequency 495 MHz using non-directional antenna
 Recorder charts (c) Frequency 654.25 MHz using directional antenna

are accepting reflected components. This feature emphasizes the point made in Section 2.3., that analysis of the distribution of the signal and correlation with reception quality can be confused by the type of antenna used. In a tree-lined road, away from buildings, the situation is clearer,

although there is marked frequency difference, due to losses caused by foliage. However, in this respect the situation illustrated by the recorder charts is misleading, because subsequent work at slower vehicle speeds showed increased scatter in the Band I measurements, traced to the response time of the recording circuits. This problem, together with the suspect linear height gain adjustment, eventually led to the conclusion that the use of antennas at low heights was unsatisfactory if results were to be quoted for 10 m. a.g.l.

The second type of measuring technique, used mainly for VHF Band III services, consisted of clusters of five 'spot' measurements, made with the receiving antenna elevated to 10 m. a.g.l. The measurements in each cluster were separated by four or five metres, in order to give some indication of local standing wave effects^(2.8). A high-power station required on average about 1500 groups of measurements.

The third method, adopted for the UHF channels, used spot measurements with the receiving antenna at 10 m. a.g.l. This approach was intended to reveal the approximate spatial dispersion of field strength within an area, assuming the distribution was log normal, i.e., the signal level being expressed as decibels relative to 1 $\mu\text{V/m}$. Based on the statistical approximation that the absolute range of variation between maximum and minimum values is 6σ , the median could be determined with 99% probability with an accuracy ρ given by

$$\rho = \pm \frac{2.5\sigma}{\sqrt{n}}$$

where σ = standard deviation of the samples

and n = number of samples taken

An accuracy of ± 2 dB for the median was regarded as reasonable, and most of the routine site test and survey work concentrated upon populated areas. Thus the majority of the measurements were made in towns and villages, providing the median field strength for each together with some indication of the statistical scatter about these values. Points were chosen to represent typical domestic sites, and attempts were made to scale measurement density to that of the population,

producing answers therefore which related to “percentage population” rather than “percentage area”. With this technique, the number of spot measurements needed to produce the median values required to forecast the coverage of a high-power station was of the order of 2000, although this depended on the terrain; in hilly areas the number of samples needed was much greater ^(2.7). Later a method known as “follow-the-contour” was adopted for smaller stations in the UHF network, in which the engineers concentrated on locating the primary contour line defining the limit of service from the transmitter, involving measurements in both urban and rural areas. In the case of VHF, measurement was continued whilst the survey vehicle travelled between populated areas, so that a substantial amount of information was subsequently available to determine “area” as well as “population” coverage.

The measurements made using a balloon-mounted transmitter antenna during site testing provided unique data. The many thousands of height gain tests, in which the measuring vehicle remained at a fixed point, and recorded reception whilst the altitude of the transmitting antenna was changed, have been a valuable source of information for this project.

By early 1961, the UK was able to contribute a large number of short-range results to help with the preparation of the future Recommendation 370 ^(1.75). Most of these came from the broadcasters, and the numbers are shown in Table 2. These results were the mean values of measurements made in cities, towns and villages, ranging in area from less than one to several tens of square kilometres.

Organization	VHF	UHF	Totals
BBC	1316	422	1738
ITA	814	27	841

TABLE 2
UK SHORT-RANGE RESULTS PRESENTED TO
THE MEETING OF EXPERTS - CANNES 1961

Mean values of field strength measurements in populated areas

2.4.3. Long-Range Results

As mentioned in 1.7., research effort was concentrated in the early days after the War on the examination of the variation of field strength with time, and many countries set up experimental programmes. The reception of signals from distant transmitters is subject to fluctuations in the constitution of the upper air creating multipath, the result of absorption, refraction or reflection. Changes in the field strength will certainly start to be apparent at relatively short distances, well within the range of 100 km assumed in the early assessments of spatial variation to be clear of such problems.

The primary difficulty concerning the resolution of the effects of upper air behaviour upon radio propagation persists - long-established theories exist, but direct confirmation by measurement is very limited. The nature of the radio refractive index of the troposphere, and the clear air effects which create multipath fading are known. Various documents produced by the ITU/CCIR specify the formulae for assessment, and others, notably (at the time of writing) Report 338^(2.9), and Report 238^(2.10), provide statistical data which allow systems to be planned with adequate safety margins. However, both of these Reports related to fixed services, in which the positions of the transmit and receive antennas are precisely located, and it is notable that they were Reports (which essentially described local experience), and not Recommendations.

Field strength measurements made in the past sixty years or so to examine the causes and effects of upper air turbulence upon broadcast signals have rarely been compared directly with contemporary data describing tropospheric behaviour. There have been projects, notably those carried out by the COST 210 and 235 Groups^(2.11, 2.12), but these dealt with frequencies above 1.0 Ghz and the quantity of evidence relating to the broadcasting bands is small. The results underline the dependence upon the detailed structure of the transmission medium, and the considerable problems of quantifying these in the detail needed to test what are, essentially, optical theories. Thus, in common with the situation already described in dealing with spatial variation, VHF/UHF propagation prediction over long distances for broadcast planning has been based upon statistical

analyses of a large database of field strength measurements.

The LDR measurement programmes set up in the UK and in neighbouring countries after 1945 revealed the general nature of abnormal propagation overland and across the relatively cold waters surrounding the UK. Experiments from elsewhere gave valuable additional information concerning the influence of sea temperature, and the effects of different types of terrain. Subsequently World-wide results became available, and a very substantial database of measurements was established. However, the description at this stage concentrates on the UK activities because these results were a major contribution in the preparation of Recommendation 370.

A typical UK LDR experiment involved the continuous field strength recording of a distant transmission at a fixed point. Because of the weakness of the signals from the distant transmitter, virtually all of the experiments had to be conducted using exposed receiving sites in open country. In terms of receiving location, the results could not be directly compared with the "50% location" datum of the field strength/distance curves produced for shorter ranges, which were based upon median values in built-up areas - usually screened by local terrain and buildings. To correct this discrepancy, some of the LDR experiments also included site variation factor (SVF) tests, the objective being to adjust the results so that they represented the "50% location" condition. This was achieved by conducting usually brief measurements at a number of typical domestic reception points within 20 km or so of the fixed LDR site, and comparing those with the levels simultaneously recorded at the latter, thereby producing a location distribution curve for the general area. This "quantified" the position of the fixed site, and an adjustment was made for the 50% location condition. *The correction vitally assumed that the temporal range of the signal in an area was unaffected by the choice of receiving site within that area.*

Up to the beginning of 1961, 137 LDR experiments were conducted by UK authorities. An "experiment" is here defined as a recording for a period of time over a single propagation path. The durations of individual experiments varied from one to 33 months, although coincidentally the 137 experiments produced a total of about 137 years of propagation recording. Some details are

shown in Table 3. these results, together with the short-range measurements listed in Table 2, were contributed by the UK in 1961 during preparatory work for the Stockholm Conference.

Organization	Duration In Months		
	VHF	UHF	Totals
BBC	559	359	918
GPO	478	100	578
DSIR	105	33	138
NPL	16		16

TABLE 3
ORIGIN OF LDR EXPERIMENTAL MEASUREMENTS
PRESENTED TO THE MEETING OF EXPERTS – CANNES 1961

The monthly totals of each contribution are shown, although the results submitted to the Cannes meeting provided individual analyses for each of the 137 experiments conducted by the four organizations, regardless of its duration

However, the LDR work did not stop; by the beginning of the Seventies the UK programme had been extended to include a further 103 experiments. The year 1971 marked the end of the LDR project which had started in 1946, although measurements from many subsequent experiments became available later. Table 4 shows the durations in months for a total of 126 experiments, for which results were available by the end of the decade.

Organization	Duration In Months		
	VHF	UHF	Totals
BBC	311	1034	1345
GPO	101	261	362
ITA	33		33

TABLE 4
FURTHER LDR EXPERIMENTS

The table shows the totals for 126 experiments, 103 of which were included in the original LDR project, and 23 were carried out by the BBC after 1971

In common with the short-range measurement activities, many critical comments were made during the work concerning the methods used, but little could be done about the most serious deficiency - data describing upper air conditions. Some information was available from the Daily Aerological Records issued by the Meteorological Office, listing the temperatures, humidities and pressures from their twice-daily radiosonde ascents. Unfortunately these did not measure the fine structure of the atmosphere needed for complete analysis, and in any case it was a time-consuming task to convert the meteorological data for comparison with the propagation measurements. However, several engineers concerned with the work drew attention to the correlation between reception recordings and general weather patterns. For many years it had been a matter of observation that abnormal levels of propagation occurred during settled periods of anticyclonic weather, and some of the LDR experiment reports described such situations^(2.13, 2.14, 2.15). It was not possible at the time to pursue this aspect in any detail, although some associated study was undertaken within the scientific area by members of the DSIR. Valuable observations were also being made by radio amateurs^(2.16, 2.17).

It would be prohibitively expensive and technically impossible to repeat now the LDR experiments which were conducted over the 25 years between 1945 and 1970, and despite the inability to relate the results to upper air data, the original records have been a unique source of information. Unfortunately, lack of resources at the time the work was carried out meant that the measurements could not be fully researched, and this aspect is discussed at length later in this thesis.

2.5. The Structure and Subsequent Development of Recommendation 370

Following the description of the measurements upon which the Recommendation was based, the structure of the international prediction is now reviewed. To do this, it is appropriate firstly to consider the basic field strength/distance curves as they existed in 1961. Intermediate development is then outlined, and finally the present contents are examined.

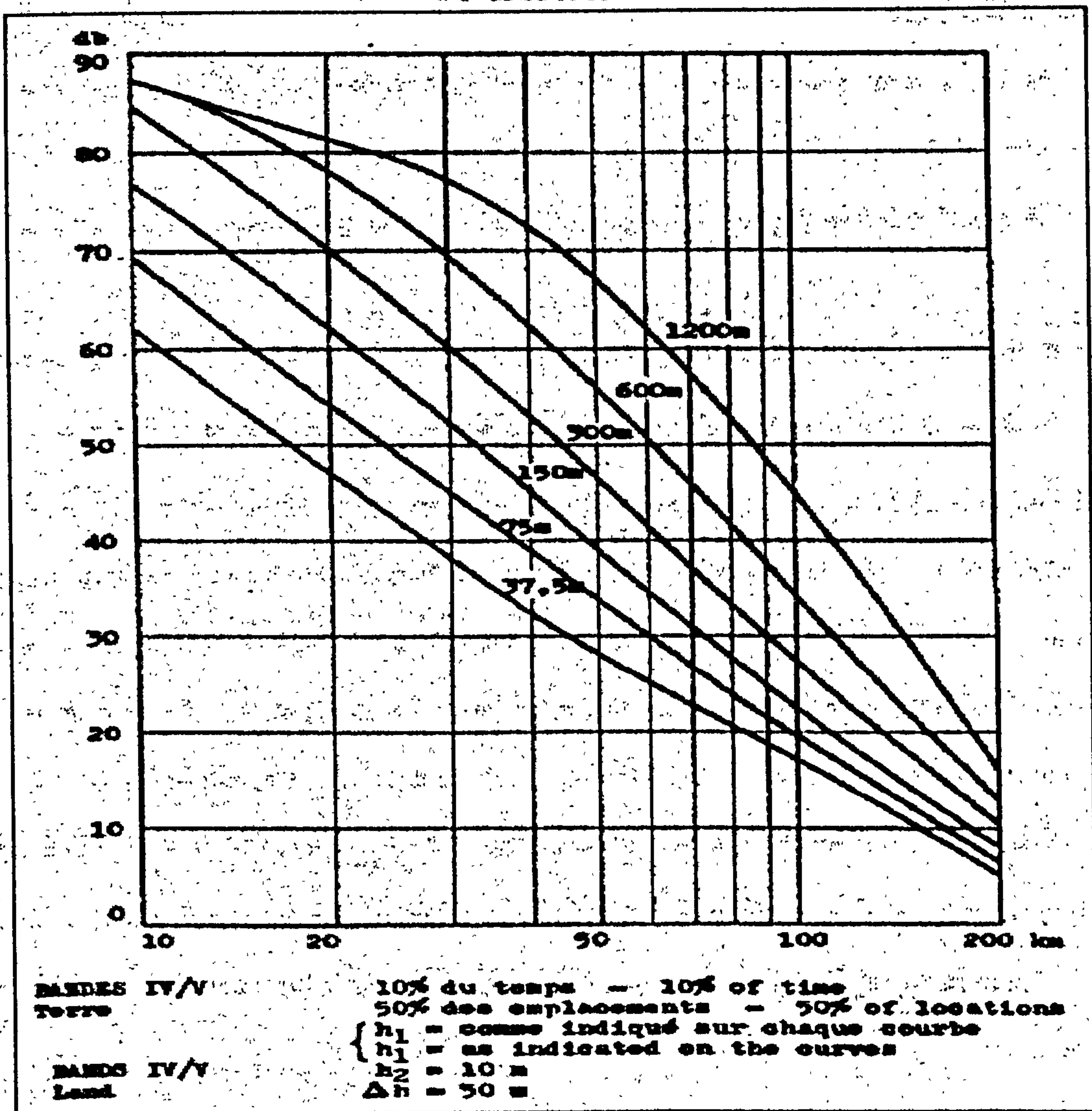


FIGURE 3
MEETING OF EXPERTS - CANNES 1961

This example of field strength/distance curve predicts overland propagation in the UHF bands (470 – 960 MHz). The curves cover a range of transmitting antenna heights (h_1) from 37.5 m to 1200 m, and assume a receiving antenna 10 m above ground level. The field strengths are those predicted to exist for 10% of the time, at 50% of the locations. They also relate to “average” terrain, having an undulation measured by $\Delta h = 50\text{ m}$ (see text)

In 1961, two sets of propagation curves were published in the first part of the CCIR report from the meeting of experts, one for VHF and the second for UHF^(1.75). They were produced for a range of frequencies, and transmitting antenna heights, and a UHF example is shown in Figure 3. It is important to note the distinction between percentage time and location on the curves, which depict the decay of field strength with distance for “50% locations”, i.e., the median value produced from measurements made within a “small area”. The meaning of the latter is discussed in more detail

later and at this stage it is only necessary to comment that the dimensions of this area were regarded as insignificant when compared to the overall path length. The effect of time upon the signal was revealed by producing a separate set of curves for a range of values, namely 1%, 10% and 50% time, each showing the field strength achieved for the stated period.

The curves assumed a receiving antenna height (h_2) of 10 m. a.g.l., and the transmitting antenna elevation was defined ("somewhat arbitrarily" in the words of the document) as its height (h_1) above the mean level of the terrain between distances of 3 km and 15 km from the transmitter. In fact the great majority of the measurements upon which the curves were based were obtained with transmitting antenna heights about 300 m. above mean terrain, and there was little evidence for the full range of heights shown in Figure 3. The information became even more sparse at longer ranges, but the Secretariat, acting on the wishes of the delegates at the Meeting of Experts, had to extend the curves to a universal range of 1000 km. Thus a further figure was published depicting decay for a single transmitting height of 300m a.g.l. for distances beyond 200 km, and a simple correction based upon smooth earth theory was devised to allow for different antenna heights at these longer ranges.

In the case of VHF, conditions over longer paths were based upon measurements made on Bands I and II, which had already been adopted by the ITU in 1953. These covered distances up to 1000 km, although again caution was advised in their use beyond 700 km. They reported conditions for three time percentages overland, 1%, 10% and 50%, and a fourth curve showing observed propagation over the North Sea for 1% time was also published. It was reported that in the Mediterranean, field strengths might exceed the North Sea values by as much as 20 dB. For mixed land/sea paths, it was advocated the sea path curve should be used if the proportion over sea exceeded 80%.

At UHF, the increased risks of attenuation caused by the terrain were taken into account by the introduction of a parameter Δh , designed to define the degree of surface irregularity. This was the interdecile range (between the 10% and 90% levels) of the heights of the terrain along the

propagation path from 10 km to 50 km from the transmitter. The basic curves were assumed to refer to a "type of rolling irregular terrain found in many parts of Europe, for which a value of Δh of 50 m. is considered representative". For higher values, reductions of up to 20 dB were advocated, although these were to be phased out over path lengths between 100 and 200 km.

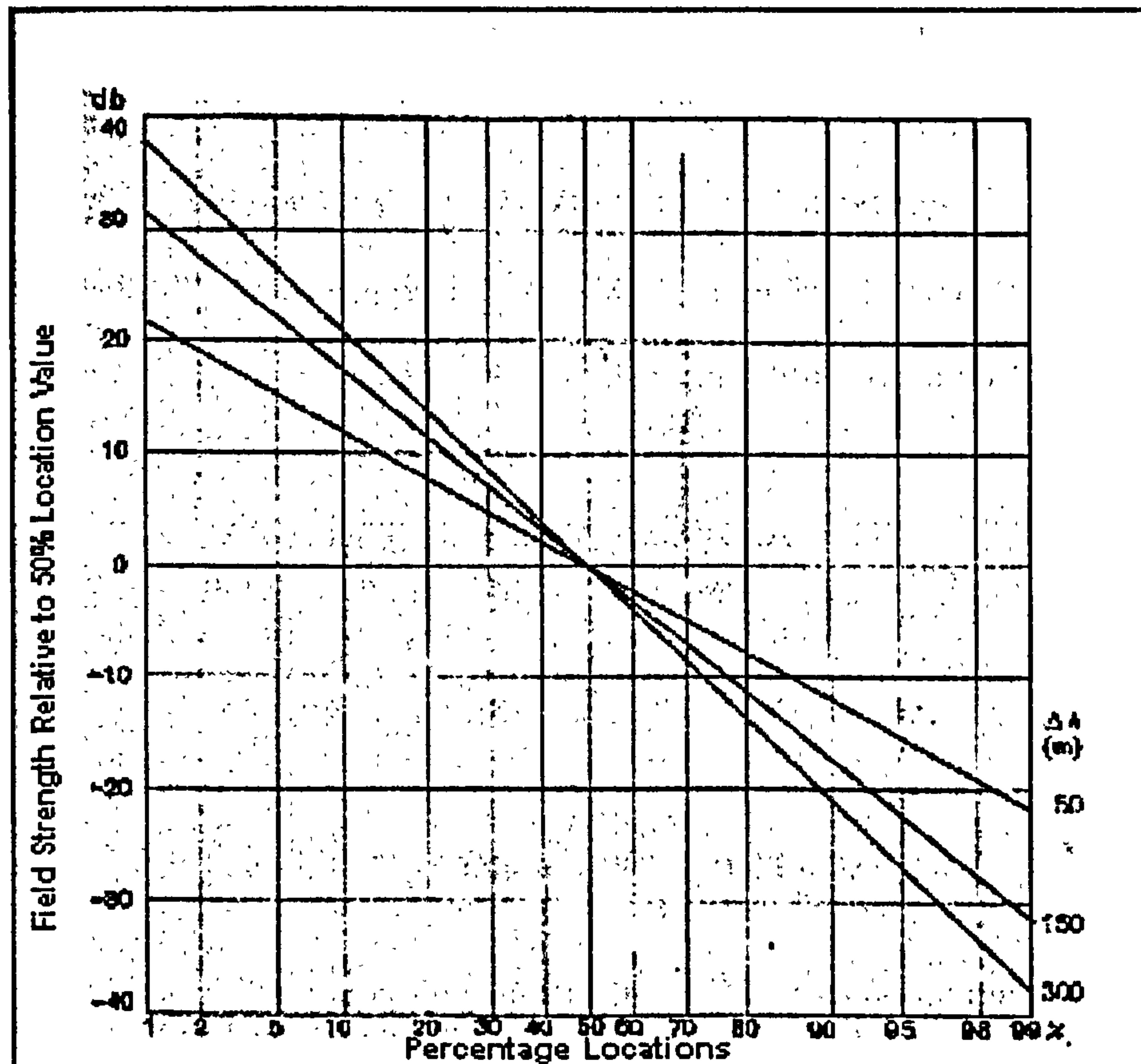


FIGURE 4
LOCATION VARIATION

The graph shows the ratio of the field strength for a given percentage of the receiving locations within a small area, to that of the 50% value, the latter being defined by the field strength/distance curves

Throughout, the field strength/distance curves claimed to represent "50% of receiving locations", based upon the statistics of field strength distribution within an "area", rather than the value at any particular point. The features which determine this distribution may be classified under three headings - multipath, the variations caused by overall path topography, and local ground cover. The first is a nebulous feature, its impact can only be detected using special receiving equipment, and it was not defined in the contributing measurements. The overall influence of path topography

was averaged by the field strength/distance curve, so in the context in which it was used in the Recommendation, location variability was intended to describe mainly the spatial statistics associated with the effects of local ground cover within the "area". Clearly the dimensions of each area and the topography from which the individual results were drawn were vital, but in 1961 the former were not defined. Figure 4 is an example of the information that was published in the report issued by the Meeting of Experts ^(1.75), predicting the spatial distribution of UHF field strength about the 50% location value. It will be seen that the relationship between field strength variation and location is expressed in terms of the ground irregularity factor, Δh . A slightly different single curve, without reference to Δh , was published for VHF, although later its application was extended to those bands.

Frequency Band	Overland or Oversea	Distance Range (km)	1% Time	10% Time	50% Time
VHF (41 – 216 MHz)	o/l and o/s	< 1000	yes	yes	yes
UHF (470 – 960 MHz)	o/l	do.	yes	yes	yes
do.	o/s (see note)	do.	yes	yes	yes

TABLE 5
PROPAGATION CURVES CONTAINED IN
RECOMMENDATION 370-1 (1966)

The overseas curves for UHF were confined to a single transmitting antenna height of 300 m. above mean terrain, and also included an additional curve for 5% time.

Table 5 lists the main propagation curves which were originally agreed in 1961, and which appeared in the Report of the Meeting of Experts. Subsequently a number of changes to the text were introduced during the 1962/1966 study period, and these were incorporated in the version of Recommendation 370 which appeared in 1966. There was also some re-drafting of the propagation curves for distances of less than 200 km in order to avoid inconsistencies in the provision for transmitting antenna height definition, which were discussed at interim meetings of CCIR Study Group V, at that time composed of specialists responsible for the contents of this Recommendation and other texts dealing with "propagation in non-ionized media". The reasons for these various modifications together with additional advice based on the experience of those undertaking research were partially explained in an important supporting CCIR Report, which had been

introduced in 1959^(2.18).

Over the next 20 years, more than 600 contributions were presented to Study Group 5 from its international membership on the subject of propagation in the band 30 MHz to 1000 MHz, the majority from the UK, and Recommendation 370 had three overall revisions. The supporting Report^(2.18) underwent five reviews. Evidence from LDR experiments and associated analyses more than doubled after 1961, and much new information emerged, described later in this thesis. But there was a reluctance to change the basic propagation curves published in subsequent versions of Recommendation 370, partly due to concern about the effects such modifications might have upon the overall plan in its transitional stages. There were reservations in some Administrations that radical modifications might demand changes to operating conditions of high-power transmitters already installed. Thus the European VHF/UHF coverage plans agreed in Stockholm in 1961 and eventually supplemented by the extensive network of relay stations, used prediction techniques largely based upon the earliest measurements to calculate interference levels.

However, a particularly significant feature added during the course of one of the reviews of the supporting Report was a means of adjusting the recommended prediction by taking account of the "terrain clearance angle" (TCA) at the receiving end of the propagation path. This was an approach originally introduced by the BBC^(2.19), and was an early attempt to improve the international prediction by using a small amount of additional detail which could be readily acquired from national maps showing the local terrain. With this, a correction was applied to the result taken from the basic field strength/distance curve, this adjustment defined by the angle measured between the horizontal at the receiving antenna and a line drawn to the highest point of the terrain along the propagation path within 16 km (10 miles in the original UK work). The principle is shown in Figure 5, which illustrates the convention used in specifying the angle. A negative angle reduced the propagation curve result, and a positive angle specified an increase. Although simple in concept, it was effective in taking account of the immediate foreground, an important feature at high frequencies.

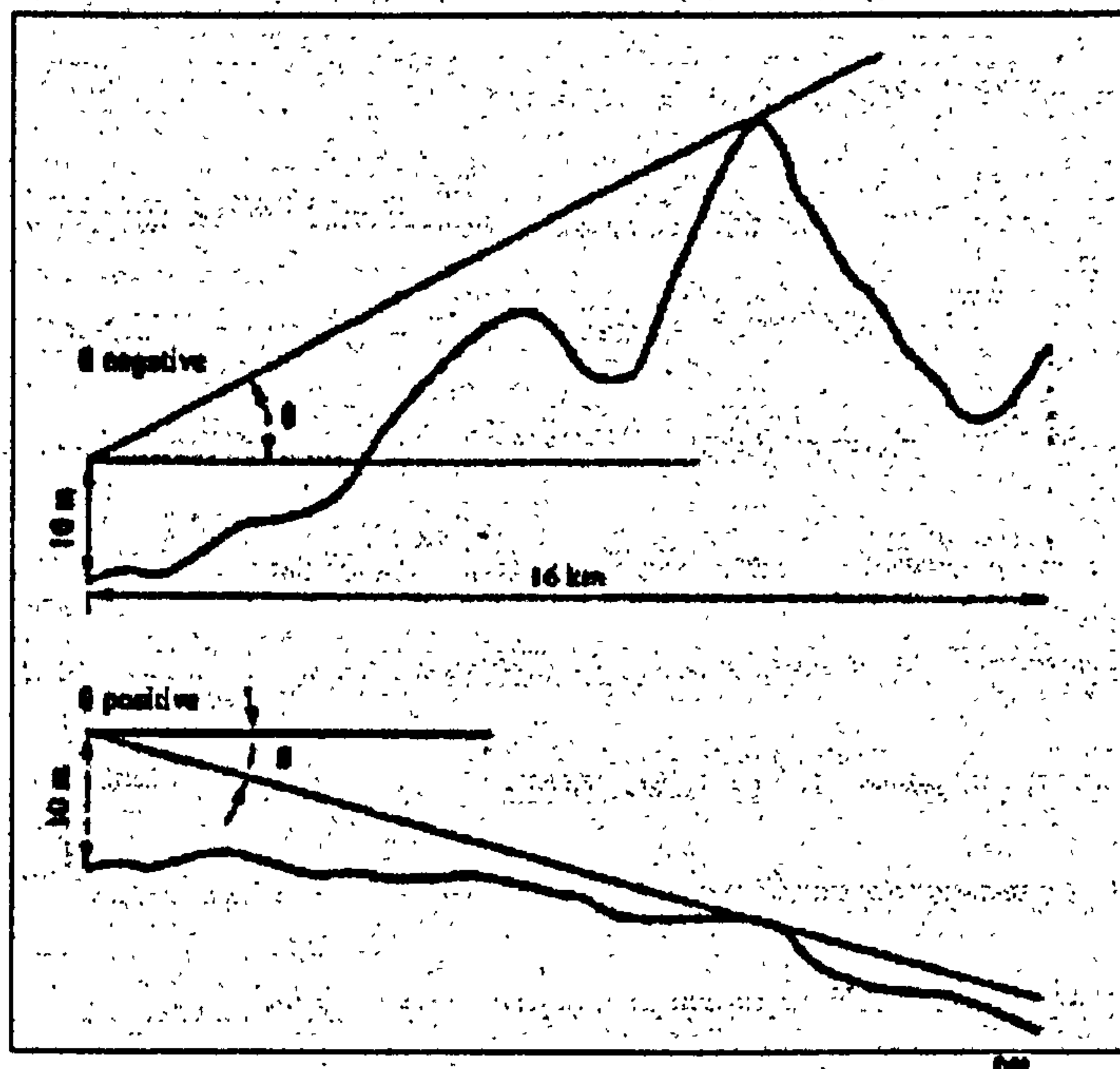


FIGURE 5
THE TERRAIN CLEARANCE ANGLE

**Correction intended to adjust propagation curve 50% location
result by taking account of local terrain**

In 1978, recognizing the increasingly important demands of land mobile services, a second Report was produced by the ITU to deal with transmission and reception using terminal antennas at low heights^(2.20). Much of the field strength prediction information contained in this Report was derived from Recommendation 370 and Report 239.

By the early Eighties, with most of the major development work on the high-power VHF and UHF broadcasting transmitters in Europe completed, but with planning of the extensive relay station networks in hand, it had become obvious that there were several serious problems with the main Recommendation and its accompanying Report. An Interim Working Party (IWP 5/5) was set up by CCIR Study Group 5 to examine the situation, and in early 1983 they produced a report^(2.21), based upon their examination of the current editions of the documents - Recommendation 370-4 and Report 239-5. This listed a number of general comments on the existing texts, the more significant of which are listed below:-

- The propagation curves had been based upon measurements made in a wide variety of receiving environments; they should be reviewed so that they referred to ideal but not exceptional reception conditions, e.g., open-site results unaffected by local ground cover.
- The terms of application of the Δh parameter should be clarified.
- There was uncertainty regarding the mix of theoretical and measured evidence in the construction of the curves, particularly obvious in the case of VHF, where the influence of ground reflection at short ranges should be apparent. This defect had so far “escaped detection” because the Recommendation internationally had been used almost exclusively for predicting interference at relatively long ranges.
- There was confusion about the corrections used to convert long-range measurements to the 50% location conditions. Different methods had been used by the various contributors.
- There was inadequate information concerning location variability and receiving antenna height gain.
- The mixed path (land/sea) prediction was unsatisfactory.

The IWP 5/5 report contained a number of editorial proposals for dealing with specific problems in the text of the Recommendation and Reports, and also included suggestions for future work. It proposed that new propagation curves might be produced by examining old data together with any new information. Consideration of the relevance of the dependence of the median field strength on the refractive index gradient was also suggested, and the application of future and existing computer methods for prediction was a recommended study item.

Unfortunately, the report produced little reaction. Much of the planning work on the high-power networks within Europe had been completed, and specialized effort was now concerned with the task of adding the many thousands of low-power relay stations needed to complete UHF coverage. Attention was concentrated on the development of detailed field strength predictions essential for those activities. The growth of computer methods and terrain databases, developed within individual countries to deal with their national problems (described in the next chapter), diminished interest in the essentially crude international method. What little international effort was available

had to be largely devoted to the development of Recommendation 370 for use in areas of the World where VHF/UHF broadcasting had yet to be introduced, notably the African continent, and this situation persisted until the end of the Eighties. However, some research was started in the UK in 1984 in response to the IWP 5/5 report, particularly fortunate because the UK was the source of many of the original measurements. Initially taking the form of comments upon the Recommendation, this work is described later in this Chapter.

The fifth version of Recommendation 370 was produced in 1986, and incorporated some of the proposals drafted by the Interim Working Party. A sixth edition was published in 1992, and the text of the seventh, which remained substantially unchanged to the end of the century, was agreed in 1996. At the time of writing the situation is being reviewed for the introduction of digital terrestrial broadcasting.

To conclude this review of the development of the document, it is useful to compare the contents of the last edition, Recommendation ITU-R PN.370-7, with the edition 370-1 agreed in 1962/1966. Table 6 lists the propagation curves shown and comparison with Table 5 shows substantial extension, although much of the original detail remains unchanged. Measurements mostly in the Western Mediterranean area have allowed the inclusion of the category of "warm sea", and the text also includes reference to results obtained in the Gulf area, defined as "hot seas", although propagation curves for these were not published.

Frequency Band	Overland Or Oversea	Distance Range	1% Time	5% Time	10% Time	50% Time
VHF (41 – 216 MHz)	o/l	<1,000 km	yes		yes	yes
do.	o/s	<950 km				yes
do.	o/s (cold)	<1,000 km	yes	yes	yes	
do.	o/s (warm)	<1,000 km	yes	yes	yes	
UHF (470 -960 MHz)	o/l	<1,000 km	yes		yes	yes
do.	o/s	<450 km				yes
do.	o/s (cold)	<1,000 km	yes	yes	yes	
do.	o/s (warm)	<1,000 km	yes	yes	yes	

TABLE 6
PROPAGATION CURVES CONTAINED IN
RECOMMENDATION PN.370-7 (1996)

The propagation curves continued to represent the field strength values exceeded at 50% of the locations, but the area from which the results are taken was defined in the last edition as a square approximately 100 to 200 m. on a side. The justification for this precise definition is obscure, and interestingly the VHF and UHF location distribution curves (Figure 4) remained unchanged from those published in 1961. This part of the 1996 Recommendation also included reference to digital modulation having bandwidths of at least 1.5 MHz^(2.22). Other improvements were also added, for example dealing with transmitting antenna heights outside the range of those shown in the curves (37.5 m to 1200 m. above mean terrain), and arrangements were introduced for conditions where the height of the transmitting antenna is negative, i.e., below mean terrain (a situation increasingly common with the growing number of small transmitting stations). Importantly, it was recommended that where terrain information was available, the TCA correction should be used instead of the Δh adjustment, reflecting negative experience with the use of the latter. Observing requests made by the 1983 IWP, some links were drawn between the field strengths predicted by the propagation curves and refractive index gradients measured in the first kilometre of the atmosphere above ground level. In the case of VHF prediction, some reference was also made to the effects of the ionosphere, specifically those caused by sporadic-E ionization.

From the foregoing it will be seen that for 40 years Recommendation 370 has been a simple means of estimating field strength levels, primarily designed for the purposes of international planning, and essential for the initial allocation of the frequency spectrum between countries. It can produce a coarse estimate of coverage, but detailed methods have been developed within many countries to predict the range of the wanted signal more accurately. Unfortunately, there has been no international consensus on these methods, and the less precise ITU Recommendation has been retained to predict the interfering field strengths from distant stations. Because the interference levels in many cases now dictate coverage, discrepancies between the prediction of coverage and experience have become apparent. To investigate these problems, detailed criticisms of the present contents of Recommendation 370, some of which have emerged from the UK research started in 1984 are described in the next section.

2.6. Comments on Recommendation ITU-R PN.370-7

The formal examination of the international prediction work passed through two discrete phases. From 1984 to 1991 it was carried out by the author under the sponsorship of the BBC, together with two colleagues in BBC Research Department. From 1991 to 1997 the work was continued by the author with the support of the Radiocommunications Agency of the DTI. During this period attempts were made within the membership of the ITU working party concerned to introduce a new international prediction. The position became more complicated with the growth of experience from the development of national plans, and the emerging need to deal with the analogue/digital conversion. Since 1997 the author has pursued his own investigations privately.

The main objective of the 1984/1991 phase was to decide between improving the ITU prediction, or devising a new model. A secondary objective was to report the status of the detailed prediction program then being used by the BBC for broadcast development, a method described in the next Chapter. To achieve these aims, the author and his colleagues assembled all the original UK measurements that had been contributed during the development of Recommendation 370, together with many results not previously examined. In fact, much of the investigation had to be spent on measurement interpretation because, as suspected, this was the source of many of the problems. For this reason the 1984/1991 BBC study was largely confined to results for path lengths not exceeding 120 km, and concentrated upon factors affecting the spatial variation of field strength.

Table 7 is the list of UK VHF/UHF broadcasting transmitters from which the information was drawn, and Figure 6 shows their locations. In the table, the "number of paths" is the total of separate propagation paths examined, and not the number of individual measurements. This depends upon the measurement technique, described in Section 2.4.2. A database of the measurements was organized, with details describing the locations of the transmitting and receiving sites, the heights and types of the antennas, the nature of the environment, and the operational

Frequency Band	Transmitter	Polarization	Number of Paths
I	Ashkirk	V	428
	Crystal Palace	V	1877
	Row ridge	V	1413
	Tacolneston	H	627
	Wenvoe	V	1488
II	Wenvoe	H	3456
	Wrotham	H	3557
III	Beulah Hill	V	3422
	Emley Moor	V	1720
	Huntshaw Cross	H	230
	Ridge Hill	V	445
	Winter Hill	V	1475
IV	Bressay	V	589
	Etshal	H	545
	Knockmore	H	299
	Skriaig	V	478
	Torosay	V	436
	Wrekin	H	3854
V	Bluebell Hill	H	827
	Crystal Palace	H	628
	Sutton Coldfield	H	3369

TABLE 7
SOURCES OF MEASUREMENT

Field strength surveys of the transmitting stations listed above provided the measurements for the BBC 1984/1991 study. The final column refers to the number of individual propagation paths between transmitters and receivers which were investigated

conditions, i.e., frequency, power, and polarization. Details of each propagation path were stored, although until 1991 the only terrain database available to the BBC was one which had been initiated during the Sixties by the Joint Radio Committee of the Nationalised Power Industries^(2,23). Originally covering England, Wales and parts of Scotland, it contained a "representative" height for each unit of a 0.5 km matrix based on the National Grid system. The representative height had been manually selected using Ordnance Survey maps, and rules were devised to reveal the maximum *range* of height that a profile might produce. Thus, where a square contained a spot height, this was recorded, alternatively if it included a valley, then the lowest height was stored. It

was a coarse system, but was a very substantial advance on earlier methods, and permitted computer processing. Subsequently, it was extended to cover the whole of the UK, and substantially enhanced for coverage planning purposes by the addition of ground cover data and population information. Relatively recently far more detailed databases have become available - at considerably greater cost.

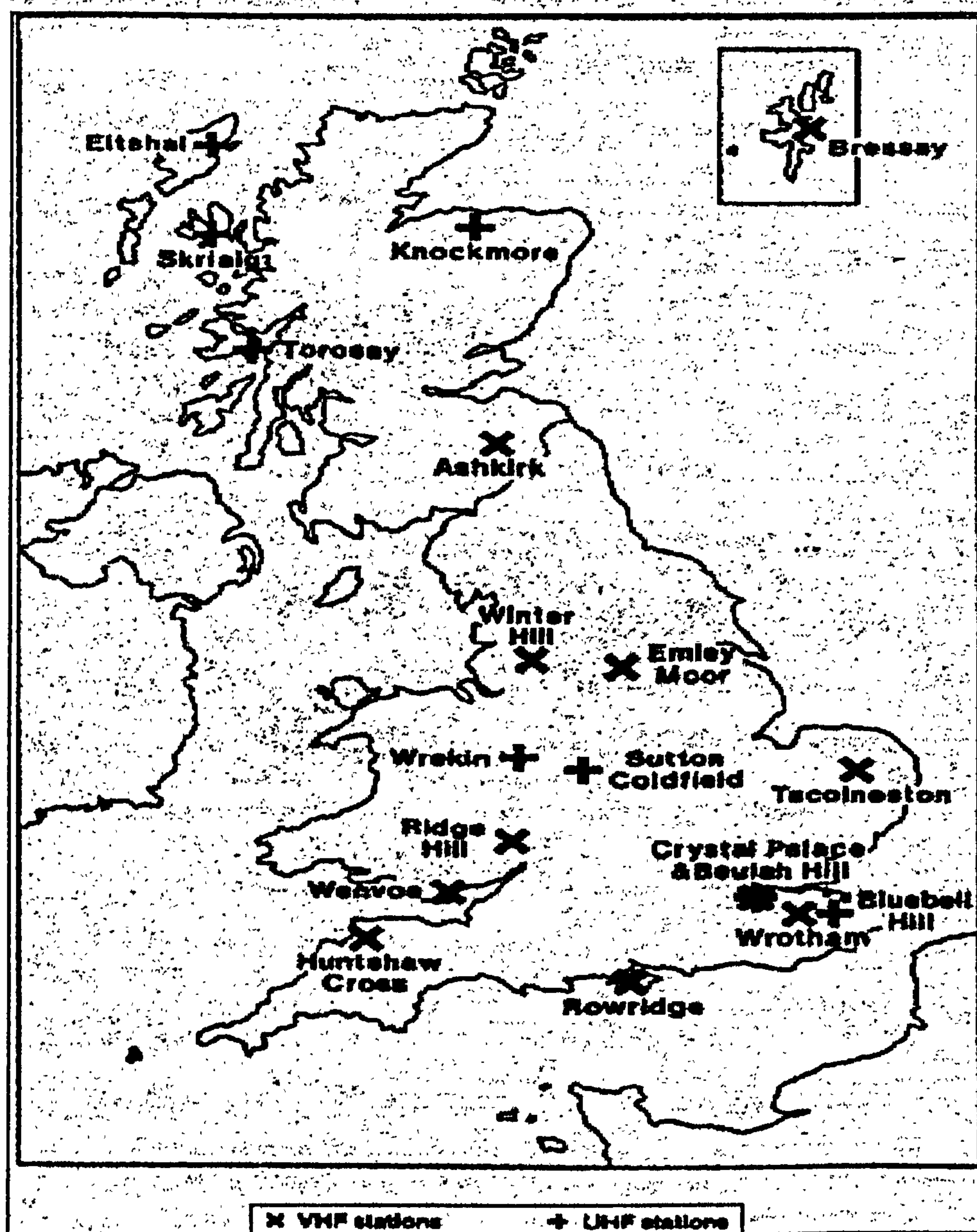


FIGURE 6
LOCATION OF TRANSMITTERS
LISTED IN TABLE 7

Analysis of the measurements and supporting information carried out before 1991 produced a number of detailed criticisms of the contents of Recommendation 370, and these were described in the report which was issued at the end of the project ^(2.24). These, and additional comments which were not published at the time, are summarized below. The first three criticisms referred to the analysis of the measurements used to construct the original nine field strength/distance curves which appeared in issue 1 of the Recommendation in 1966, and which were listed in Table 5 above. They are absolutely fundamental because they deal with the original measurement analysis, and affect the foundation of the curves which remained largely unchanged in the final version.

i) The basis of the propagation curves - ground cover: Whereas the measurements upon which the curves were originally based were made at short ranges in mainly urban areas, those at the longer distances were obtained from experiments conducted at open, exposed receiving sites. Nominally the curves throughout represent 50% locations, but as already described the methods of deducing this condition changed at the distance where measurements to determine spatial distribution were replaced by experiments to assess temporal change. The latter is discussed later, at this stage attention is focused on the location aspect at short ranges, i.e., the relationship of the median values of individual groups of measurements to the 50% location curve.

The results shown in Figure 7 have been taken from an investigation into results in Band I ^(2.25). Median values from groups of measurements in built-up areas have been plotted against the Recommendation 370 VHF curve for the appropriate transmitting antenna height. In the Recommendation this curve represents results for the frequency band 30 to 250 MHz, and some overall bias must be expected when results from the lower end of this range are used for comparison. However, having regard to the fact that the plots shown in the Figure are only the median results and that contributing measurements are widely distributed about each point, the extent of scatter is substantial. The range of the individual distributions is very roughly approximated by a location variation curve of the type shown in Figure 4, although as will be seen later, this is an approximation which is also subject to criticism. One reason for the scatter of the medians about the single curve shown in the Figure is local ground cover. Most of the short-range

results were obtained in urban and suburban areas, thus the density and nature of local ground cover was influential. Results from small towns and villages in rural areas will generally lie above the curve, those from urban centres will fall below.

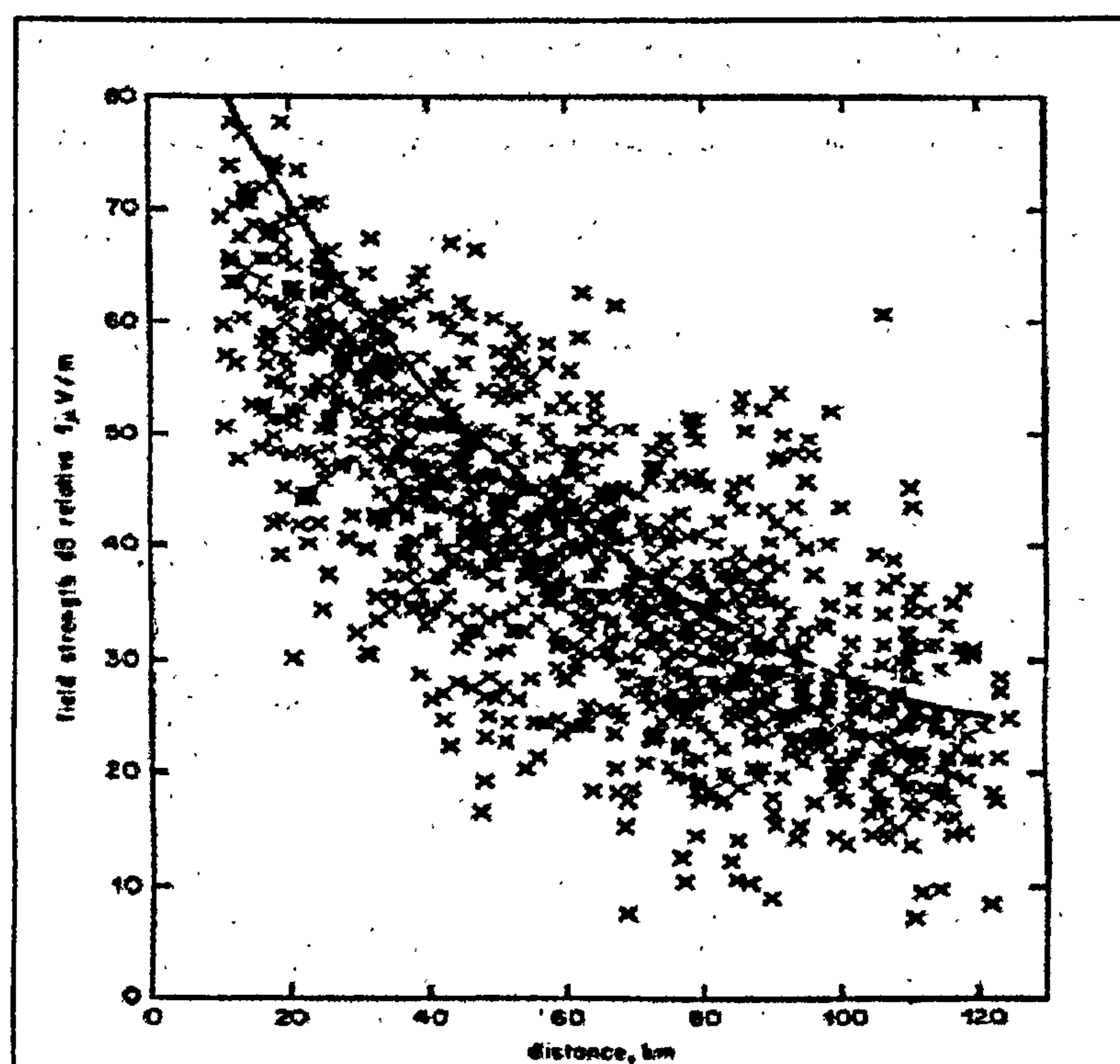


FIGURE 7
DISTRIBUTION OF VHF MEASUREMENTS

Results are median values of field strengths in populated areas, each point derived from groups of between 10 and 200 measurements.

ii) **The basis of the propagation curves - local terrain:** The position of an individual plot with respect to the single curve in Figure 7 is also influenced by the terrain in the vicinity of the receiving antenna, and here it is necessary to distinguish between those features within the small area represented, and those in the propagation path beyond the area. The internal variations are dealt with in iii) below, initially the external effects are considered. In the case of the larger conurbations of the UK, many of these are in valleys - historically they expanded around watering places - and here the urban measurements were subject to local terrain diffraction loss in addition to that caused by ground cover. Although, as will be seen later, the details of the parameter are questioned, some indication of the effect of local terrain was obtained by using the TCA correction

to measure the local terrain situation of 4,600 test locations within 180 towns and villages. This sample produced an average clearance angle of -0.6° , with interdecile limits of $+0.2^\circ$ to -1.9° , confirming that the majority of the results for distances up to 120 km had come from measurements made in valleys. Using these results and the last edition of the TCA correction curve to appear in the CCIR Report 239-6, produces the contents of Table 8. Taking VHF as an example, the 50% location results shown in the Table suggest that the correction for the predictions made for areas having the average terrain is - 2.5 dB.

Percentage Location	Report 239-6		Recommendation 370-6	
	VHF	UHF	VHF	UHF
	dB	dB	dB	dB
10	4	5	3	12
50	-2.5	-7	-1	1
90	-14	-15	-7.5	-8

TABLE 8
TERRAIN CLEARANCE ANGLE CORRECTIONS
OBTAINED FROM CCIR PUBLICATIONS

Results obtained for 4,600 test locations in populated areas.
Report 239-6 information is dated 1986, whereas
Recommendation 370-6 was issued in 1995

However, the Table also shows the results arising from the use of a later edition of Recommendation 370, revealing differences between the two ITU documents which occurred when some of the material of Report 239 (dated 1986), including a revised TCA section, was incorporated in the Recommendation. This was done without material correction to the basic field strength/distance curves published in the latter, and the net result was to raise the field strength predicted using this method, particularly serious in the UHF case. Effectively this nullified the use of the correction in the important 50% location case. To date this anomaly is unresolved, but is mentioned here because this information was used for some years (see also further comment under (iv) below).

iii) **The basis of the propagation curves - size of area represented:** This is probably the most important anomaly. Mentioned above, the 50% location results used to construct the basic curves

of the Recommendation for short distances were derived from measurements made within what were described as "small areas", now defined in its latest edition as having sides approximately 100 by 200 m. From points i) and ii), it will be appreciated that the nature of the terrain and ground cover will determine the analysis and the meaning of the prediction. Clearly, both will also be influenced by the size of the area.

Early measurements concentrated on centres of population, and the concept of a "small area", introduced without defining its dimensions, emerged. These extended from hamlets to large towns, they varied in area from 0.5 to over 30 square kilometres, and the significant numbers measured in the early stages have been shown in Table 2. At lower frequencies, the field strength levels achieved for 10%, 50% and 90% of the lengths of chart-recorded measurements were used to report results, and within this interdecile range many approximated a normal distribution. This distribution of field strength was also assumed for the purpose of UHF survey, still regardless of the size of the area, and the technique of measurement was based on this assumption. Hence the presumption in the ITU Recommendation that variation with location within "small areas" observes these characteristics. In fact, in an early investigation by the author, of the total of 2,579 results used to construct the spatial distribution curves in the Recommendation (Figure 4), only 11 came from areas which could be enclosed by a 100 m. square (the 200m by 100m situation has not been investigated). The curves representing the distributions are virtually identical in the report of the Meeting of Experts (dated 1961)^(1.75), and the latest edition of the Recommendation.

The example illustrated by Figure 8 is typical of the results that the original analysis produced. In this case, two hundred groups of UHF measurements, made within an area of 22 square kilometres enclosing the town of High Wycombe, gave the results shown, here plotted as to show the relationship between field strength and percentage locations. Already described, measurement locations were chosen largely on the basis of population density; thus the abscissae more precisely report "percentage population"; although noted at the time, the influence of terrain was largely ignored. The immediate requirement was to plot median and distribution values of field strength in terms of the basic parameters of the prediction, i.e., distance and height of the transmitting antenna

above mean terrain. Quite different conclusions emerge if the whole measured area is subdivided into small parts (approximately 100 m. square), and investigation is concentrated upon those within which the land is substantially flat. The overall range of field strength is then revealed to be composed of a series of small distributions, separated from others largely by the effects upon propagation of local changes in ground level. The slope and character of each individual distribution is determined by the height of the receiving antenna and the local ground cover.

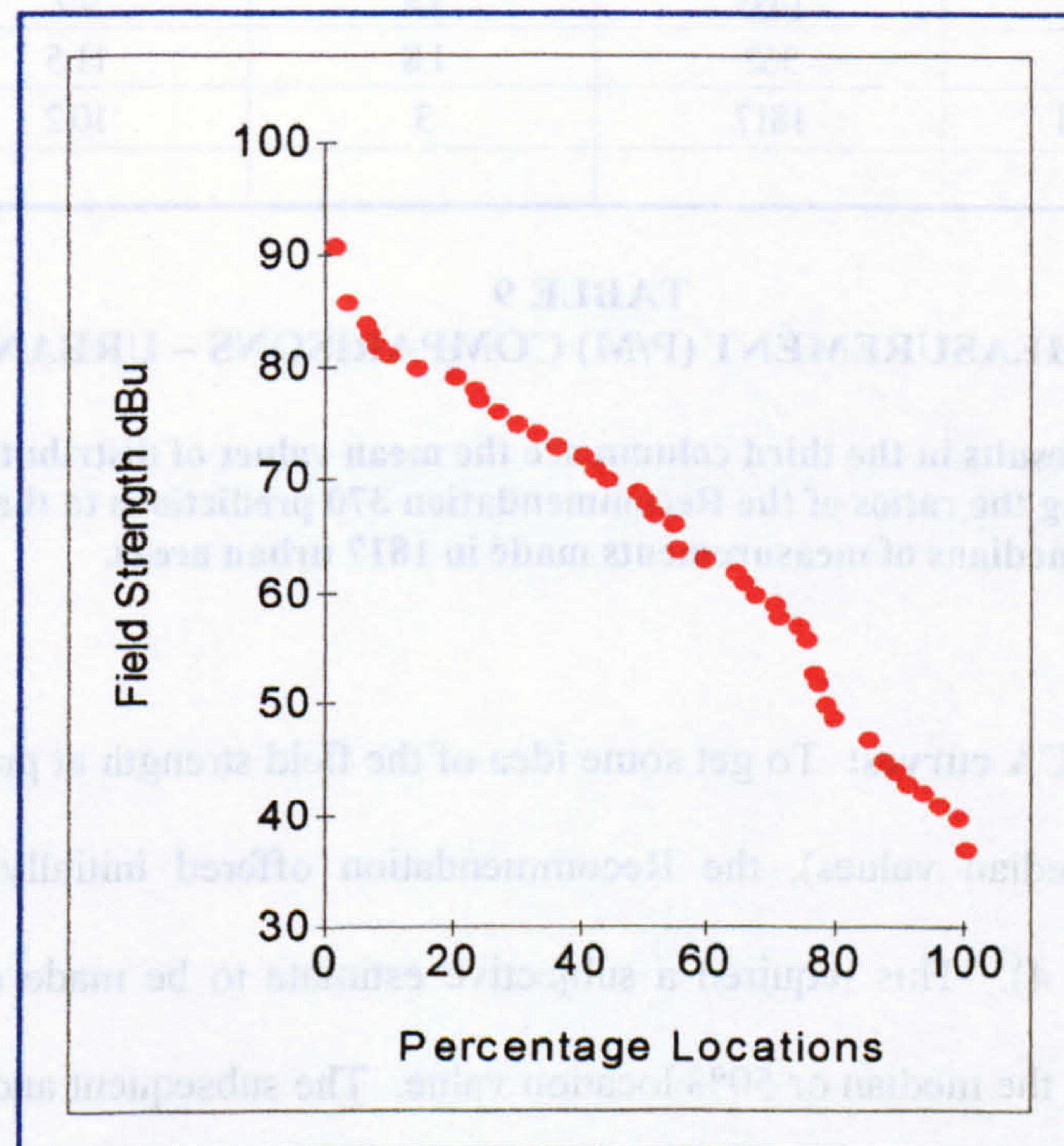


FIGURE 8
DISTRIBUTION OF UHF FIELD STRENGTH
MEASUREMENTS WITHIN HIGH WYCOMBE

**Results obtained within an area of 22 sq. km., location of measurements
 selected to represent population density**

From the original measurements, a median field strength of 66 dB μ V/m was recorded for High Wycombe, with a location variation represented by a standard deviation of 14 dB. For comparison, the Recommendation 370 propagation curves gave a median of 60 dB μ V/m, and the method would predict 10 dB for the location variation (using the “one-size fits all” Figure 4). Individual errors of this sort were common, and it is useful to provide a general indication of the accuracy of the basic international prediction. Table 9 has been prepared from the first phase of the examination which

ended in 1991 ^(2.24). Here the Recommendation 370 predictions have been compared with the median values of 1817 urban areas, within which a total of 32,000 measurements were made. These medians were used in the construction of the propagation curves defined in the original prediction, so this comparison has produced a reasonable result.

Frequency Band	Sample Size	P / M Mean (dB)	Standard Deviation (dB)
VHF	1455	3.4	9.7
UHF	362	1.8	11.5
Overall	1817	3	10.2

TABLE 9
PREDICTION / MEASUREMENT (P/M) COMPARISONS – URBAN MEDIANS

The P/M results in the third column are the mean values of distributions showing the ratios of the Recommendation 370 predictions to the medians of measurements made in 1817 urban areas.

iv) **The origin of the TCA curves:** To get some idea of the field strength at precise points within these areas (not the median values), the Recommendation offered initially just the location variation curves (Figure 4). This required a subjective estimate to be made of the “percentage location”, i.e., relative to the median or 50% location value. The subsequent and more useful TCA correction, described in 2.5., was intended to eliminate the population weighting, and quantify the result in terms of the local terrain. Table 10 shows the results of applying the prediction, with and without the TCA correction, to each of the measurements made throughout the 1817 areas used to produce the results in Table 9. Considering the method is here being used to predict detailed results at precise receiving locations, the mean errors of the uncorrected results of Table 10 are surprisingly low. The predictions are generally high, and the standard deviation is very substantial. Use of the TCA correction reduces the scatter, suggesting the concept is correct, but introduces too much additional attenuation. This overcorrection is partly due to a fault in the derivation of the international version of this factor. The form of the TCA curve has been shown in Figure 5, and it was produced within BBC Research Department by plotting the angle θ measured at individual reception sites as a function of the difference between the measurement and the prediction for that

precise location. However, when the correction was proposed for international use, a much wider selection of results was used, largely consisting of the median values of measurements previously employed as a basis for the Recommendation 370 propagation curves. Instead of obtaining angles for the individual measurements, a single value was chosen to represent each area from which the median field strengths were derived. The choice of location was subjective, selected to be topographically representative of the area and hence assumed to be suitable for correlation with the median field strength value. Furthermore the influence of ground cover upon the results was not always taken into account. Thus the correction was not reliably defined solely upon the evidence of the effects of local terrain upon reception at measured points, and overstated the attenuation. A later attempt to rectify this may have accounted for the anomaly already mentioned in (ii) above.

Frequency Band	Sample Size	No TCA P/M Mean (dB)	No TCA S.D. (dB)	With TCA P/M Mean (dB)	With TCA S.D. (dB)
VHF	20138	2	10.6	-2.7	7.9
UHF	12369	0.9	13.8	-3	10.9
Overall	32507	1.7	12	-2.8	9.7

TABLE 10
PREDICTION / MEASUREMENT (P/M) COMPARISONS – ALL RESULTS

The P/M results in the third and fifth columns are the mean values of distributions showing the ratios of the Recommendation 370 predictions to each of the individual measurements made in 1817 urban areas. The values in the adjacent fourth and sixth columns are the standard deviations.

v) **Correction for receiving antenna height:** The propagation curves assume a standard height of the receiving antenna of 10 m. a.g.l.. However, new analysis of the measurements immediately raised an old problem, one that had been obvious for several years. Many of the records of VHF field strengths at 10 m. a.g.l. had been made at a lower height and a linear height gain had been added - and for some time the value of this correction had been suspect. It was based upon a very limited number of measurements, and practical difficulties meant that most were made at open locations. Short paths were chosen to minimize the risks of fading, and in these restricted conditions a linear correction was shown to be adequate in the early VHF work. It was applied to measurements in both rural and urban areas, but discrepancies were confirmed when some research

work was carried out at the start of UHF transmissions ^(2.7). It was shown that in urban and suburban areas there was seldom a linear relationship between field strength and height, because of the additional loss caused by local ground cover. In suburban areas in particular, there was a rapid increase in height gain at about 9m. a.g.l., at which point the antenna rises above local ground cover, predominantly two-storeyed houses. This last factor particularly affected the early VHF results, where the standard height used was 30 ft. a.g.l. (9.1 m). However, by the early Sixties the emphasis in broadcasting was on the development of UHF networks, and nothing was done about the old VHF records. The problem was overcome at UHF by making measurements with the receiving antenna at 10 m. a.g.l.

The subject of receiving antenna height gain was important for mobile radio services, where prediction for the rapidly expanding services had to rely initially upon evidence gathered by broadcasters, although this was rapidly overtaken by many specialized studies, including extensive work undertaken in Japan ^(2.26). It was also important for the development of the broadcasting FM service operating in Band II, with the growth in mobile listening. Much new information on the subject began to appear. A search through the references confirmed that the universal application of a linear height gain to the measurements database was certainly inadmissible, and this emphasized the importance of conducting further investigation using the original measurements, i.e., before conversion. This allowed the influence of ground cover and other important factors to be examined in detail, and provided a reliable basis for further analysis of propagation and coverage.

vi) **Directivity of the receiving antenna:** Apart from the concerns regarding the corrections for height of the receiving antenna, the type used (directional or non-directional) also influenced the measured field strength, as already discussed. In practice, the overstatement of field strength mostly affected the forecast coverage of the VHF services. Problems were likely to occur at short ranges, the original measurements having been made almost exclusively with non-directional receiving antennas in built-up areas. Comparisons between VHF and UHF propagation ^(1.69, 2.27, 2.28)

provided some information concerning the differences between results in the television bands I and III, and those obtained during later work in bands IV and V, although this research concentrated upon the greater diffraction losses experienced at the higher frequencies. To some extent the influence of antenna directivity was obscured by the substantial frequency separation, and by the use of different measurement techniques. The more recent detailed analysis of the VHF chart records was productive, and identified areas where the use of non-directional receiving antennas certainly influenced the coverage estimates. Particularly affected were the forecasts for the VHF/FM services in Band II, which were based upon relatively few in-band measurements, supplemented by extrapolation from Band I results. Band II measurements did not support a "theory continuum" between the Band I and the Band III evidence, and at the time this was attributed to a number of factors which undermined reliance on these results, nearly all attributed to various propagation uncertainties when using horizontal polarization.

vii) **Frequency:** In terms of the frequency range covered by Recommendation 370, since its introduction it has been extended to cover the VHF/UHF bands up to 1,000 MHz., and there is now evidence to extend this information to the top of the UHF band, i.e., 3.0 GHz. However, there has been criticism in the past that whilst the two sets of propagation curves, the first covering VHF and the second UHF, provide adequate distinction between these two relatively well-spaced frequency bands, there was reason to support further sub-division between the three bands which occupy VHF. Covering the nominal range from 30 to 300 MHz, this includes an important part of the spectrum where the effects of ground reflection are apparent. This was one of the comments made in the 1983 report by the IWP ⁽²²¹⁾ - they were concerned that the curves failed to identify these phenomena. Further work tended to support the action taken in the Recommendation, although this was based upon the conurbation median results which seldom revealed ground reflection. However, the recent investigation into the use of non-directional receiving antennas using the detailed measurements provided clarification, and exposed the influence of frequency over the band from 30 to 300 MHz. The effects were particularly noticeable at the shorter ranges, i.e., less than 100 km, and in open country, where the impact of ground reflection was often apparent.

viii) **Polarization:** This is a feature which receives similar comment to that just made concerning frequency, although it was not considered in the preparation of Recommendation 370, primarily because effects on the basic results covered in its text seemed generally superficial. It was not felt that the addition of some rather conflicting and intangible evidence would materially affect a simple prediction. For many years the main planning interest in the subject was associated with coverage, rather than basic propagation. For example, the use of horizontal polarization meant that the directivity of a single receiving dipole antenna could be used to reduce interference problems. Similarly, a frequency plan consisting of a mix of vertical and horizontal assignments to transmitters could achieve greater coverage, again because interference between co-channelled stations could be reduced. However, there are situations where distinctions between polarization reveal important information about field strength distribution, both spatial and temporal. For example, the spatial range of UHF field strength measured with the receiving antenna at a fixed height within towns is significantly greater when horizontal polarization is used ^(2.6). Another important spatial feature which has theoretical support is often apparent at the lower frequencies, where field strength levels of vertically-polarized signals at a height of less than one wavelength above the ground exceed those of horizontally polarized transmissions ^(2.29, 2.30). There are also many results showing distinct differences between the various forms of polarization in respect of their effects upon multipath. However, it was concluded that although it does have a direct influence on propagation, primarily in its impact upon field strength distribution, it was a detailed aspect best dealt with at a later stage in a future prediction method, and to this extent confirmed the original Recommendation decision. Certainly it affects the assessment of coverage.

ix) **Overlap between the TCA and Δh corrections:** Doubts about the former have already been mentioned, and these were confirmed in the re-examination of measurements. Reasons for doubting the efficacy of the Δh correction were first expressed in the sixth issue of the supporting Report 239, published in 1986. In the seventh issue of the main Recommendation (1996) it was recommended that if the TCA information is available, this should be used in place of the Δh adjustment, following criticisms about the value of the Δh correction from several countries.

Originally introduced in the Recommendation for use only at UHF, it was extended to Band III in 1966 ^(2.31), and then to Band II ^(2.32). However, a detailed computer analysis of nearly 30,000 individual VHF/UHF measurements and associated predictions carried out by the author during this project confirmed the combined application of the two corrections certainly overestimates path losses. The TCA correction applied on its own produces a marginally better overall result, although the results are frequency-dependent, and the proposals as they stand in the current Recommendation need review, in any case already required following the remarks in iv) above.

x) **Specification of transmitting antenna height:** The height above mean terrain concept, employed in the Recommendation, is an inadequate parameter, certainly for the type of undulating terrain which the prediction represents. As described in 2.5., it quantifies the height of the transmitting antenna by its altitude "above mean terrain", i.e., the mean level of the ground along the propagation path between 3 and 15 km from the transmitter. Re-analysis of the measurements showed the correction to be at best misleading.

The archives contained many measurements of value for this particular study. Notably, there were the balloon experiments to determine the optimum antenna heights for new transmitting stations, although unfortunately this is probably the source of the unsatisfactory parameter adopted in the Recommendation. In these early tests, necessarily very limited by the time factor, normally only one height gain experiment was conducted on a particular radial bearing from the transmitter. The results were then applied to all other survey measurements in that particular sector in order to determine the optimum height for the transmitting antenna. Tests in which several height gains were obtained along a single radial produced quite different conclusions, as described below.

It is first necessary to comment on the family of heights shown in the Recommendation. At the time of the preparation of the original curves, there was little evidence to support the full range shown, i.e., from 37.5 m. to 1200 m. above mean terrain. As mentioned before, most of the measurements came from the UK, and nearly 75% were in the range 200 to 400 m. above mean

terrain. This is demonstrated by **Figure 9**, a histogram in which the effective height in 36 directions separated by 10° intervals of azimuth has been derived for 16 UK broadcasting sites from which the early field strength measurements came ^(1.64). Later, information from mainland Europe and the USA provided supplementary data regarding greater heights, but most of these results were obtained from transmitting stations sited on isolated hills and mountains, generally with high antennas, and surrounded by relatively flat service areas. Subsequent work has shown that this is the type of terrain – approximating the smooth, plane earth situation – that supports the height above mean terrain approach. It is not appropriate for the undulating terrain represented by the great majority of the UK field strength measurements.

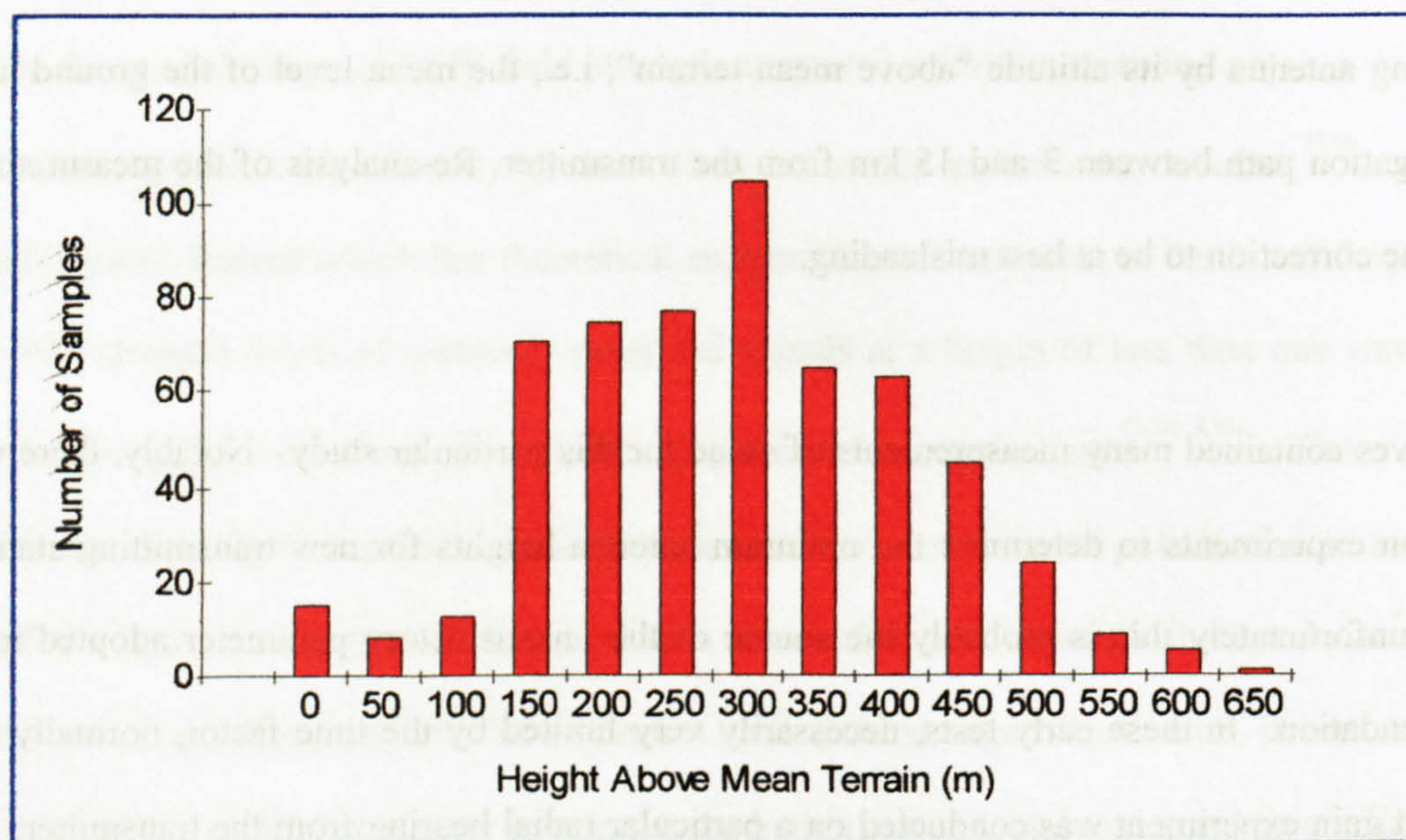


FIGURE 9
TRANSMITTING ANTENNA HEIGHTS

This histogram has been produced using the heights above mean terrain of the antennas of 16 UK broadcast transmitting stations. At each, results have been obtained at 10° intervals of azimuth

Re-examination of the measurements confirmed the inadequacy of a single height gain to represent each profile. The increment gained by raising the transmitting antenna is determined by many features in the overall path, and not just the average height of a part of it. One detailed example of the many hundreds of results is shown in **Figure 10** ^(2.24). Here measurements have been made at

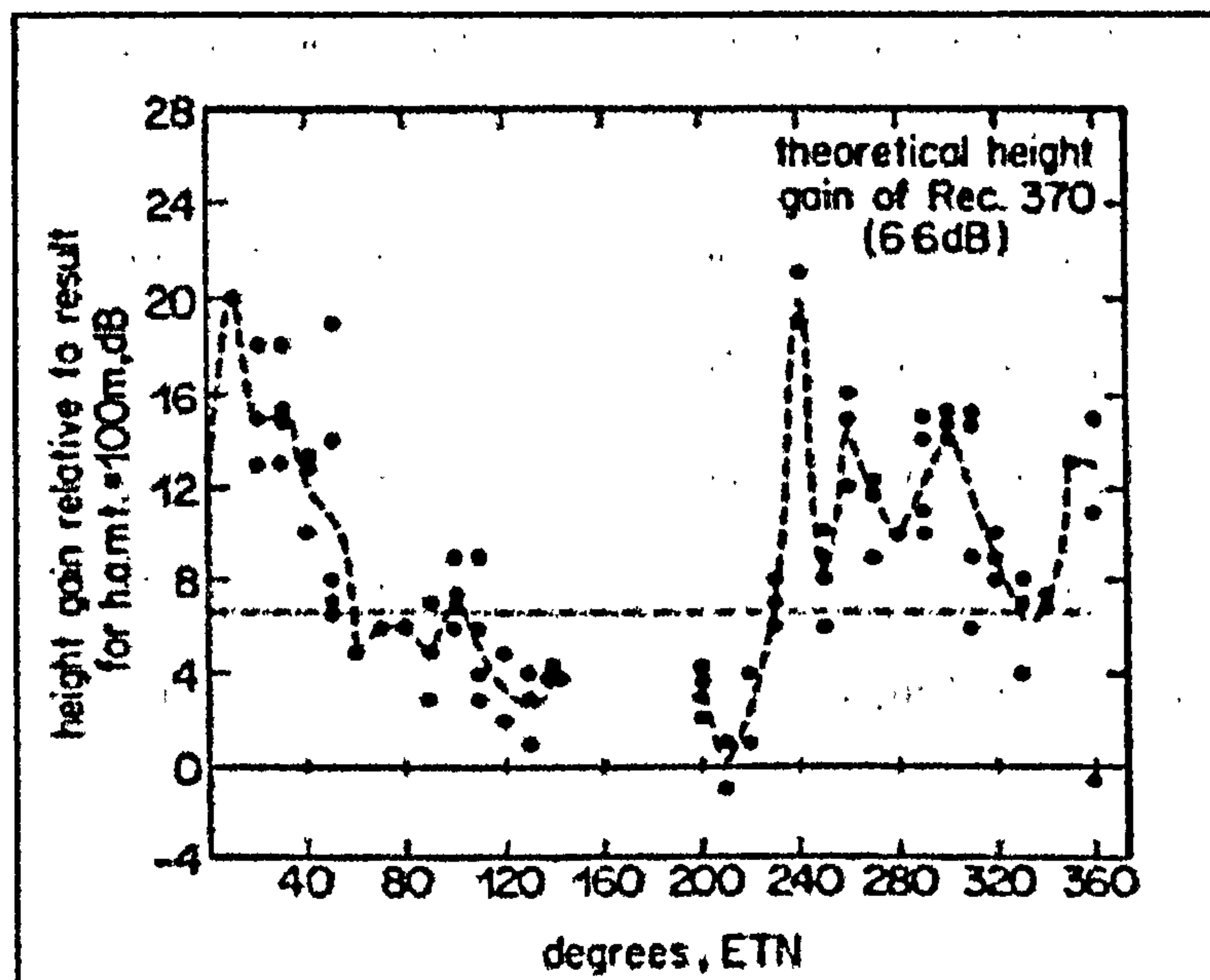


FIGURE 10
CRYSTAL PALACE HEIGHT GAINS

Measurements of increases in field strength as Band I transmitting antenna was raised from 100 to 200 m above mean terrain. Results shown on bearings east of true north from transmitting site.

about 100 locations in the London area surrounding the Crystal Palace transmitting station, whilst the effective height of the transmitting antenna above mean terrain was raised from 100 m. to 200 m. The ordinate value is the height gain relative to the field strength measured when the transmitting antenna was 100 m. above mean terrain for each radial, and results have been plotted at intervals of 10° of azimuth. Measurements of height gains are shown as solid points, and the overall average around the transmitter is recorded as a dashed line. The theoretical average height gain derived from Recommendation 370 for the conditions shown would be 6.6 dB (shown as a dash-dot line), but there are substantial variations. The least departure from this prediction exists in those directions where the land is flat and relatively open, i.e., to the east, along the Thames Estuary. Significant differences occur where the ground profile is undulating, for example along the North Downs in the southern quadrant, to the north-east in the Essex/Suffolk borders, and north of west, in the approaches to the Chilterns. Similarly, the dense urban development across the London Basin affects local results. Wide differences can also be seen between height gains measured along individual profiles. An investigation of the detailed results of an increase in height

of the transmitting antenna from 100 m. to 200 m. for this particular site test produced a much greater increase in population coverage than was inferred from the original prediction.

Of course, the real international value of the curves of the Recommendation rests upon their ability to predict the extent of interference over relatively long distances, where evidence for antenna height change was based upon a simple correction as described in Section 2.5. However, recent work on long-distance experiments, involving the additional complication of temporal changes in field strength, has confirmed that height gain decreases with distance, its principal effect being the determination of horizon range.

Temporal variation: The above criticisms generally concern problems arising as a result of inadequate definition of spatial variation, both in the analysis of measurements and in the parameters employed in Recommendation 370. This final comment relates to preliminary observations which emerged as a side product from the work which started in 1984, concerning a similar lack of precision in defining certain aspects of temporal variation, i.e., fluctuations caused by upper air changes. These problems became apparent well within the range of 100 km or so, previously assumed in the preparation of the basic propagation curves to be largely unaffected by temporal changes, although early reports had already demonstrated their presence^(2.33, 2.34). The re-examination of the spatial measurements endorsed four long-standing criticisms of the analysis of the original LDR data:-

- As mentioned before, all the experiments, regardless of their duration, were regarded as providing an equal contribution to the overall assessment of the nature of temporal distribution. Figure 11 shows the individual durations of experiments conducted between 1946 and 1974 which were examined in the review. They ranged from 38 lasting less than one month to one of more three and a half years. It is demonstrated later that the introduction of a standard period and the application of meteorological statistics which can be related to propagation behaviour profoundly affects the analysis.

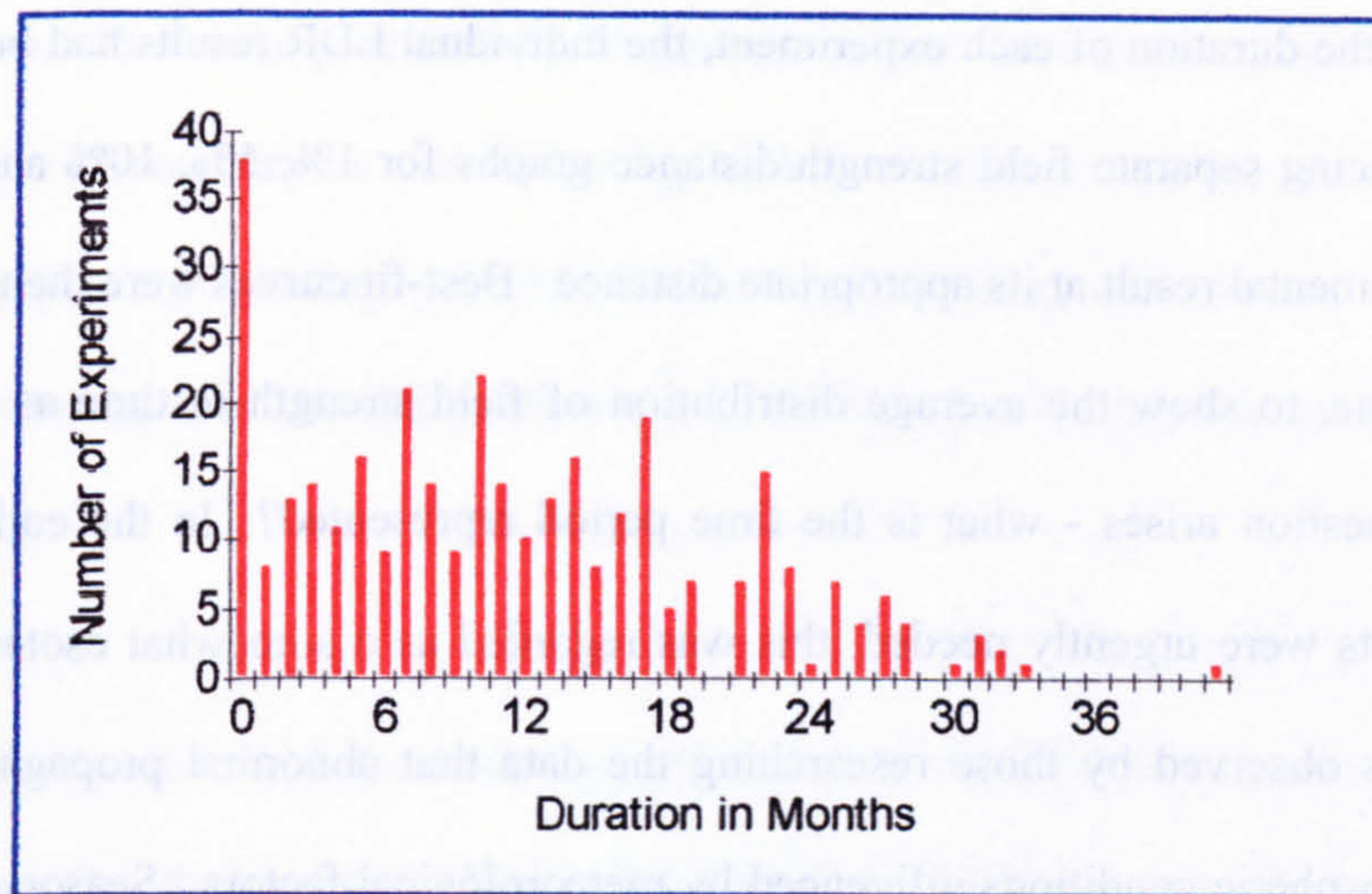


FIGURE 11
DURATIONS OF LDR EXPERIMENTS

Individual durations of 338 LDR experiments

- The method of deducing the “50% location” datum (the SVF correction) so that it corresponded to that used at shorter ranges was suspect. There were clear inconsistencies between the conclusions reached concerning spatial variation at short range and those assumed for the longer paths.
- Certain calculations used to predict coverage which involved the long-range predictions, notably the method of estimating multiple interference levels resulting from the reception of signals simultaneously from several sources, overlooked important factors which had been revealed in experiments.
- Virtually all the LDR measurements were made between approximately 0800 and 2300 hrs. daily, because the primary interest was in the planning of broadcasting networks, originally operating only during this period. During continuous monitoring of transmissions on overland path lengths of about 100 km, bursts of high-level signals were observed during the night. Although broadcasting eventually extended into the night hours, increasing evidence of this nocturnal activity was not included in the propagation statistics, which had been based upon daytime measurements.

The four basic criticisms concerning temporal variation which gained substance during the 1984 - 91 study are now described in more detail.

Firstly, concerning the duration of each experiment, the individual LDR results had been originally combined by producing separate field strength/distance graphs for 1%, 5%, 10% and 50% times, plotting each experimental result at its appropriate distance. Best-fit curves were then produced for each percentage time, to show the average distribution of field strength in time as a function of distance. But a question arises - what is the time period represented? In the early days when planning instruments were urgently needed, this was regarded as a somewhat esoteric point, and rejected, but it was observed by those researching the data that abnormal propagation occurred during certain tropospheric conditions influenced by meteorological factors. Seasonal connections were noted, and annual results were needed to reveal the full range of variation. An indication of the range within one year is illustrated by the example in **Figure 12**.

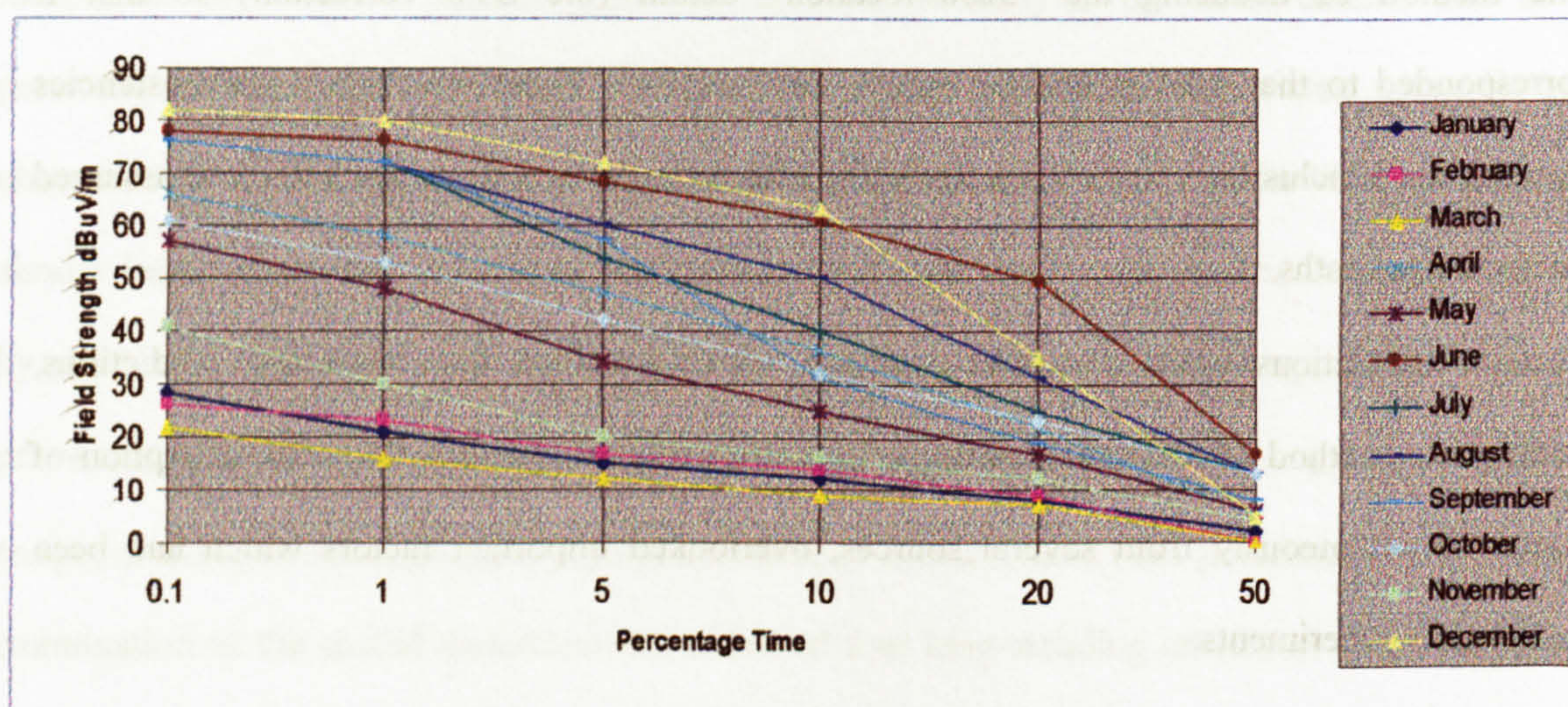


FIGURE 12
MONTHLY DISTRIBUTIONS OF FIELD STRENGTH

Scheveningen to Happingburgh 774 MHz, 1962

This gives the monthly results for one year from one overseas LDR experiment, with the transmitter at Scheveningen on the Dutch coast, and the receiver at Happingburgh in Norfolk, a path length of 200 km. It is relevant to note that the results from the original experiment (which lasted 18 months) were 79 dB μ V/m (0.1% time), 68 dB μ V/m (1.0% time), 47 dB μ V/m (5.0 % time) and 31 dB μ V/m (10% time), and these were the values which were contributed in the preparation of

Recommendation 370. In the year for which results are shown, the highest abnormal field strength was recorded in December; in the following year (not shown) it was August. Inevitably, experimental results representing periods of less than one year were biased. Fortunately, the surviving records contained the information needed to examine the problem in depth later in this project.

The second criticism involved the technique of deducing the 50% location datum of the LDR results, and it has already been described in 2.4.3. how the LDR experiments were adjusted using the SVF corrections. The validity of these adjustments depended on the assumption that the temporal range of the signal in an area was unaffected by the choice of receiving site within that area. A brief review of the results during this first stage of the work indeed confirmed that the high field strengths occurring during periods of abnormal propagation (approximately < 5% time) were independent of the location of the receiving site. However, for longer percentages of time when conditions were normal, the temporal *range* was affected by the prominence of the receiving site. Abnormal propagation produced high field strengths at the screened sites representative of the 50% location standard, but under normal tropospheric conditions reception levels were much lower than those recorded at the exposed sites. Thus, contrary to the previous assumption, the temporal range of the signal in an area was affected by the choice of receiving site. This suggested the need for urgent revision, because if proved, the use of the earlier SVF corrections would have distorted many of the LDR results upon which the international prediction was based.

The third criticism also arose during the preliminary SVF investigation, and concerned an associated feature of coverage planning, namely the calculation of multiple interference, intended to predict the combined effect of several interfering signals. It is not necessary to go into the mathematical basis for this process, other than to mention that it consists of adding the amplitudes of interfering signals, or multiplying the probabilities of occurrence, depending upon the correlation between them. Furthermore, it is an aspect which is not specifically mentioned in Recommendation 370, because it does not relate to the prediction of field strength of a single signal. However, the recent work questioned methods of assessment which assumed there was no

correlation in either the time or location domains between co-channel signals received at a single antenna. Re-examination of the measurements showed that positive correlation can exist, particularly during periods of abnormal propagation, and this is related to the angle between the propagation paths of incoming signals.

The fourth and final criticism takes account of periods of abnormal propagation not previously included in the evidence upon which the Recommendation is based, namely those which occur nocturnally, mainly on overland paths. It is assumed this can be caused by the descent of subsidence inversions after sunset which combine with radiation inversions, the process being disrupted by convection which commences around dawn. Concern within broadcasting was first expressed in the early Eighties when reports were received of interference to new, overnight services which were then being introduced. However, there were few measurements to investigate.

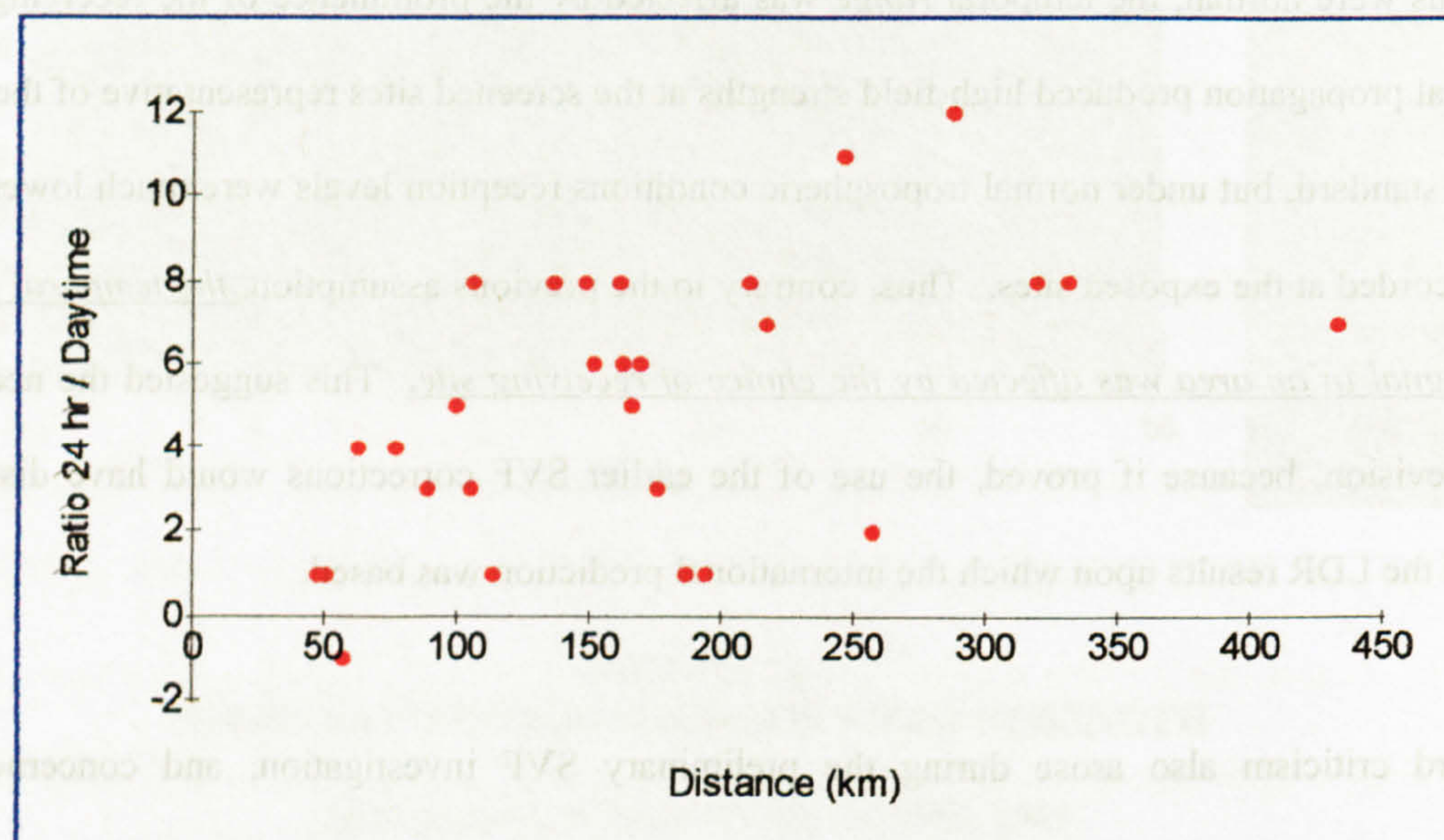


FIGURE 13
RATIO OF THE 24 HOUR TO DAYTIME ANALYSIS

The graph shows the ratio of the temporal ranges (0.1 to 50% time) of signals measured over 24 hours to those recorded during the period 08.00 to 23.00 as a function of path length

A search of unpublished UK archive material has since produced data from 14 UK experiments,

and the COST 210 project^(2.11) provided measurements in the upper part of the UHF band for a further nine overland paths. Later many more results were obtained from abroad. In particular, the Finnish broadcasting organization Oy Yleisradio Ab (YLE) carried out a most thorough programme extending over several years, and the author obtained many contributions from this source. Investigation of some of these measurements produced the information shown in Figure 13. This shows the results of comparing temporal ranges of the measurements (0.1% - 50% time) on 30 paths as a function of distance. The ratio of the 24 hour / daytime analysis for each of the 30 paths is plotted, the term "daytime" being used to describe the period covered by the earlier measurements used in the construction of Recommendation 370. It can be seen that enhanced propagation occurred on these overland paths during the night - only one of the 30 paths produced a negative result, although there is evidence that the trend decreases with distance. The results showed that two maxima occurred – one before midnight and the second from 0400 onwards.

2.7 The International Scene in 1991:

The work by BBC Research Department which produced some of the observations described above on the contents of Recommendation 370, ended in 1991. In December of that year, international action on the subject was taken up by the CCIR. Working Party 5B was formed, and this was asked to study the possibility of replacing the Recommendation (the author was nominated Rapporteur of this group). They assembled measurement data and opinions from broadcasters and land mobile radio services around the World, and tested some national prediction methods. The next chapter deals with the development of alternative methods, and the attempts to achieve international consensus.

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3. The National Demands for Greater Precision

3.1. Summary

The relatively simple prediction technique needed for the important early stages of international VHF/UHF broadcast network planning did not offer the accuracy needed to plan, specify and construct transmitting installations. For example, it was important to ensure that each new station achieved required service areas. In the early days this could only be achieved by detailed measurement of test signals radiated from a temporary transmitter. On the other hand, without international agreement, nothing could be done to change the prediction of the field strengths of unwanted, interfering transmissions. Therefore, the planning process consisted of the comparison of measurements of the wanted signal with predictions of the unwanted. However, the introduction of computers in the late Fifties offered the chance to improve prediction over all distances, and research into this aspect was started in those countries having the necessary resources. This Chapter examines the course of these activities between 1991 and 1997, which included an international project initiated by the UK.

The chapter starts by discussing the accuracy of prediction, because unless this is assessed properly, the whole analysis of the value of a particular method can be misleading. Failure to accept this fact accounted to some extent for the difficulties in reaching international accord on the introduction of improvements, in any case complicated by differences in national objectives and resources. The development of techniques based upon ray theory is described, and various examples are reviewed. The feedback of experience upon theory introduces the need for empirical adjustment of the prediction models, leading eventually to a method devised within the UK which briefly received reluctant and conditional international approval.

3.2. The Accuracy of Prediction

To quantify the accuracy of a field strength prediction model it is customary to compare its results with measurement, but inescapably measurement itself is subject to error. There are two stages in measurement when mistakes can be introduced, the first of which occurs when the equipment is calibrated. This procedure requires a low-power transmission to produce a very restricted field, within which the effect of distance or the diffraction loss of an intervening obstacle can be calculated with high accuracy – assuming the validity of optical theories. Thus, paradoxically, the accuracy of measurement depends upon prediction, because the receiving equipment can then be calibrated by comparing measurement of the transmission with the predicted field. A serious error at this stage is likely to be detected, and the process is discussed in the next section.

The second and more likely opportunity for error occurs during subsequent field work. Precautions can be taken against the risk of a discrepancy caused, for example, by accidental power changes at the transmitter in the course of measurement, but inevitably mistakes can occur in the operation of the receiving equipment. Experiments have been conducted to reveal the likely extent of such errors, and the results from one are reported here^(3.1).

Measurements of reception from a local UHF transmitter were made at 200 open sites within an area of about 15 square kilometres. Open sites were chosen because ground cover increased the spatial scatter of the local field strength distribution. The propagation path lengths were short (all less than 5 km), thereby concentrating on spatial effects and minimising the influence of temporal changes. The measurements were then repeated, ensuring that the receiving antenna at each location was at precisely the same point as that chosen in the first survey. The differences between each of the 200 pairs of measurements resulted in the histogram shown in Figure 14. The result is a slightly skewed distribution having a median value of zero and a standard deviation of about 2 dB. These errors will have been introduced during measurement, and even during this detailed experiment it was impossible to trace the origins of any other than the largest differences.

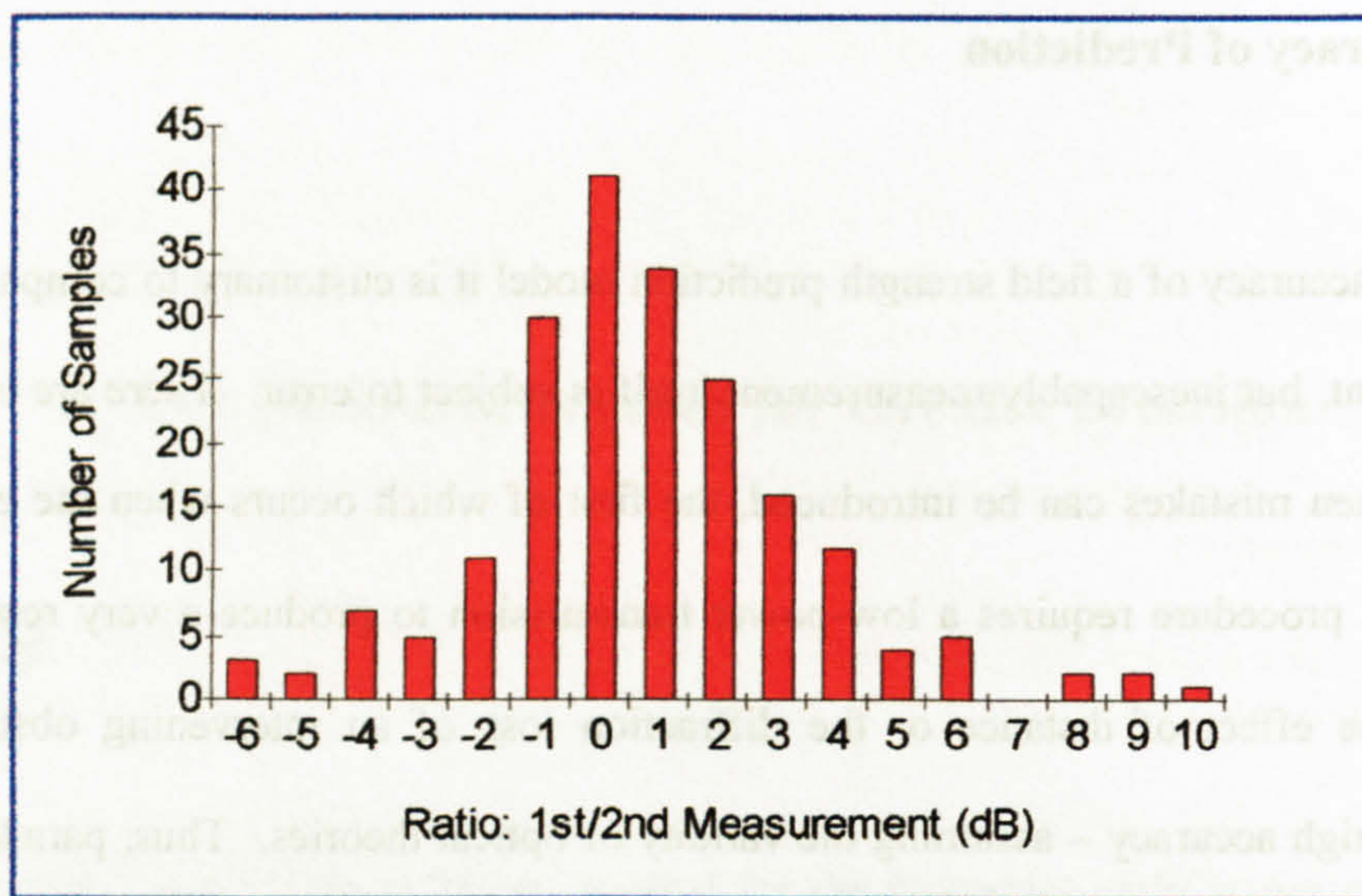


FIGURE 14
BASIC ERROR OF MEASUREMENT

Ratio of first to second result derived from two successive field strength measurements made at 200 locations – identical receiving antenna position used for each pair.

Measurements at the same receiving sites were also made of five other more distant transmitters (path distances from 26 to 76 km). Distributions between their pairs of measurements all showed a greater variance than those demonstrated in Figure 14, caused by random fluctuations in the propagation paths over the time taken to repeat each measurement. This was confirmed by recording reception over a period. Examination of similar short-range results in other broadcasting bands revealed a similar dimension of error, which appeared to be substantially independent of frequency.

Much greater differences appeared between repeated measurements even in flat, open terrain clear of ground cover, when the location of the second observation was slightly changed. This was an important factor to investigate because it demonstrated the detail needed to describe the propagation path and the complexity of the prediction method in order to achieve a stated precision. A third series of measurements was made in the experiment, keeping the receiving antenna at the same height above ground but this time selecting reception sites within about 20 m. of those used previously. Comparison between the third result and the mean value of each of the pairs of the first series again produced a normal distribution with zero median, but this time having a standard deviation of about 4.5 dB.

Investigations of the type described above exposed the different conclusions that can be reached when measurements are not made in identical locations, or in sufficient density. Of course, when the original site test and survey measurements were made, the objective was to determine the extent of coverage of a particular transmitting station, and this was judged on the results of the methods then used, as described in the previous Chapter. Not surprisingly, re-examination of these records by the author confirmed that quite different conclusions would often have been reached with slightly different measurement locations, underlining the subjective nature of the process. Even more serious discrepancies could be introduced in the final stage of coverage interpretation, when the measurements were used to introduce field strength contours, or other means of illustrating the estimated coverage of the transmitter.

The foregoing emphasizes the fact that the comparison of prediction with measurement must be carried out having fully interpreted all the contributing factors. In essence, what does the measurement represent? Does it quantify the spatial or temporal distribution of field strength? If the former, within what area; if the latter, for what period of time, and is this aspect affected by location change? Does the prediction method match the specification of the measurement with which it is compared? In the past, the accuracy of various methods has been reported by their originators, usually revealing very good results. But almost invariably these have been obtained by comparisons with their own measurements, which have also been used in the development of the prediction technique.

Comprehensive and thoroughly researched measurements are clearly essential for prediction development, but as will be seen, progress during the important years of broadcasting development was slow. This was unfortunate, because a reliable prediction method has the potential to produce a more efficient and realistic statement of the field strength distribution around a transmitter than the routine measurement techniques so far used in broadcast development. It obviously cannot compete in the clearly defined point-to-point calculation, but in virtually all point-to-area situations, the measurements used to plan the broadcast services necessarily had to be limited to avoid prohibitive expense.

3.3. Prediction Techniques Based Upon Ray Theory

3.3.1. The Early Work

Having considered the fundamental question of accuracy, the development of techniques over the past 50 years which have attempted to offer greater precision than Recommendation 370 is now examined.

The first chapter of this thesis discussed the original approach to prediction, aligned with the contemporary understanding of the physics of radio propagation. It interpreted the concepts of wave transmission using ray theory, and ignored the development of the quantum theories which emerged early in the twentieth century. The detailed methods used to plan VHF/UHF broadcasting networks were devised long after the concept of wave/particle duality had been established, and continued to rely upon the classical electromagnetic/optical theories. This thesis does not open up that discussion, although it is a matter of observation that the concepts of the nineteenth century do not satisfactorily explain some of the phenomena revealed in this study.

The early work of Sommerfeld^(1.45) introduced the distinction between space and ground waves; in effect the former are those which can be detected by a receiver within line-of-sight of the transmitting antenna, and consist of the direct and ground-reflected components, whilst the latter include those diffracted around the curvature of the earth. To these was later added the contribution reflected from the earth's layers, ionospheric and/or tropospheric. Subsequent studies by many workers produced practical versions of the Sommerfeld theory, including three extensively used in the early broadcasting developments^(3.2, 3.3, 1.35), but of course these methods concentrated upon the propagation problems encountered using frequencies below 3.0 MHz. The nature of the boundary formed by the earth's surface was primarily considered in terms of its conductivity and permittivity. Some years were to pass before migration of broadcasting services to higher frequencies introduced the diffraction/reflection problems of the detailed shape of the surface.

The early VHF/UHF prediction attempts were confined to the analysis of various field strength measurements, and the application of ray theory to single path profiles, laboriously produced. For line-of-sight paths, modified free-space curves were deduced from the measurements, and where diffraction occurred, simple models were devised to estimate losses. It was not until the early Fifties that the underlying mathematical theory was analysed in any detail^(3.4, 3.5). Although these were relatively complex treatments, they led to the introduction of more practical approaches, initially developed for simple boundary states between the earth's surface and the space above it. Thus the surface was assumed to be flat, or was described using simple geometry, for example, obstacles were represented as knife edges or cylinders. To illustrate the development of VHF/UHF prediction, various practical techniques are now outlined.

3.3.2. Antenna Calibration Prediction

This is an appropriate starting point, because the simple prediction needed for the calibration of receiving antennas involves very short distances over flat ground, ideally free of surrounding vertical surfaces likely to cause disruptive multipath propagation. The receiving antenna is placed in a "standard field", an environment in which the spatial distribution of field strength from a known source can be predicted theoretically with considerable accuracy, using ray theory. In the early form used by the BBC for VHF calibration^(3.6), the signal was radiated from a dipole across a flat, open area, and measured over a range between 30 and 70 m. from the transmitting antenna. In these near-ideal conditions, reception was assumed to consist of the vector sum of the direct ray, i.e., the free-space component, and the ground-reflected contribution. With the terminating antennas at low heights, the reflection coefficient of the ground for the small grazing angles is substantially -1, and for the purposes of the calculation the amplitude of the reflected ray was assumed to equal that of the direct ray. The path geometry can then be used to predict the field strength E at points along the path, and the predictions compared with the measurements to deduce a correction factor for the receiving equipment. In order to ensure predictable ground reflection, a standard field for this type of calibration always used horizontal polarization, thereby minimising

non-phase reversal problems associated with vertical polarization at small angles of incidence.

A similar calibration process was initially used for UHF work, but it soon became obvious that modifications to the technique were required. As described in Chapter 2, field strength measurements at the higher frequencies were made with the receiving antenna at 10 m. a.g.l., whereas VHF work had been carried out with the antenna at heights of between three and five metres. Calibration with the UHF antenna at 10 m. a.g.l. using the method described above meant that the angle subtended at the ground by the reflected ray was large, even at the maximum distance available for calibration (70 m.). There were doubts about the validity of phase reversal, and the reflection factor. The shorter wavelengths meant that the path difference between the direct and ground reflected rays could range from under a wavelength to a few wavelengths, introducing a risk in which small mistakes in measuring the heights and separation between the antennas could result in significant errors in calculating the standard field. To reduce these risks, UHF calibration was initially carried out with the terminating antennas mounted at a height of 1.0 m. a.g.l., but errors persisted. Table 11 shows comparisons of predictions with measurements from 186 VHF and 92 UHF calibrations carried out by BBC Research Department over a period of 15 years. These involved a total of 1,216 separate measurements (each calibration required a maximum of five observations, spaced at 10 m. intervals between 30 and 70 m. from the transmitting antenna). The distributions for both frequency bands were log-normal, and using the approximation that 99% of the area under a normal curve lies within $\pm 2.5 \sigma$ of the median, it will be seen that whilst the VHF results are reasonable, the UHF limits are approaching ± 6 dB.

Frequency Band	Sample Size	Mean Error (dB)	Standard Deviation (dB)
VHF	865	0.3	0.8
UHF	351	-0.8	2.3

TABLE 11
ANTENNA CALIBRATION DISCREPANCIES

Distribution of the ratio prediction/measurement obtained
from BBC Research Department antenna calibrations

Unreliable UHF calibration led in 1974 to the introduction within BBC Research Department of a method designed to overcome the uncertainties caused by ground reflection. This employed prediction of the field behind a thin, vertical screen, and was based upon the optical principle of Huyghens in which each element of an expanding cylindrical wavefront produces a secondary wavelet. The principle is described elsewhere^(3,7) and only a brief description of the application is given here.

The secondary wavelets arrive at the receiving antenna with different phases dependent upon the distances travelled. The field strength will be affected by these secondary wavelets to an extent determined by the geometry of the construction, and is quantified in terms of Fresnel integrals. The latter express the co-ordinates of an amplitude diagram (Cornu's spiral), which reveals the phase relationships between adjacent elements on the wavefront. Introduction of the thin screen interferes with reception, and the nature of this can be predicted. The result quantifies the diffraction loss behind an obstacle in terms of a dimensionless parameter v , thus:-

$$v = s \sqrt{\frac{2d}{d_1 d_2 \lambda}}$$

where s = the height of the obstacle above the line of sight path

d = total distance, transmitter to receiver

d_1 = distance, transmitter to obstacle

d_2 = distance, obstacle to receiver

λ = wavelength of transmission

Comparison of the predictions with measurement of the field provided a reliable means of equipment calibration. The layout and dimensions of the practical calibration system are shown in **Figure 15.**

The conditions did not correspond with the ideal required by theory, notably that the transmitter-edge distance d_1 and the edge-receiver distance d_2 should be large compared with the wavelength,

and that the screen should be thin, perfectly absorbing and infinite. The secondary screens were added to minimize ground reflections on each side of the main screen; in their absence energy reflected from the intervening ground upset calculations of the wavefront at the diffracting edge and at the receiving antenna. Nevertheless the technique yielded acceptable results. About 100 measurements made during the installation of the equipment confirmed the improvement - at UHF a median error of +0.1 dB was recorded, with a standard deviation of 0.3 dB.

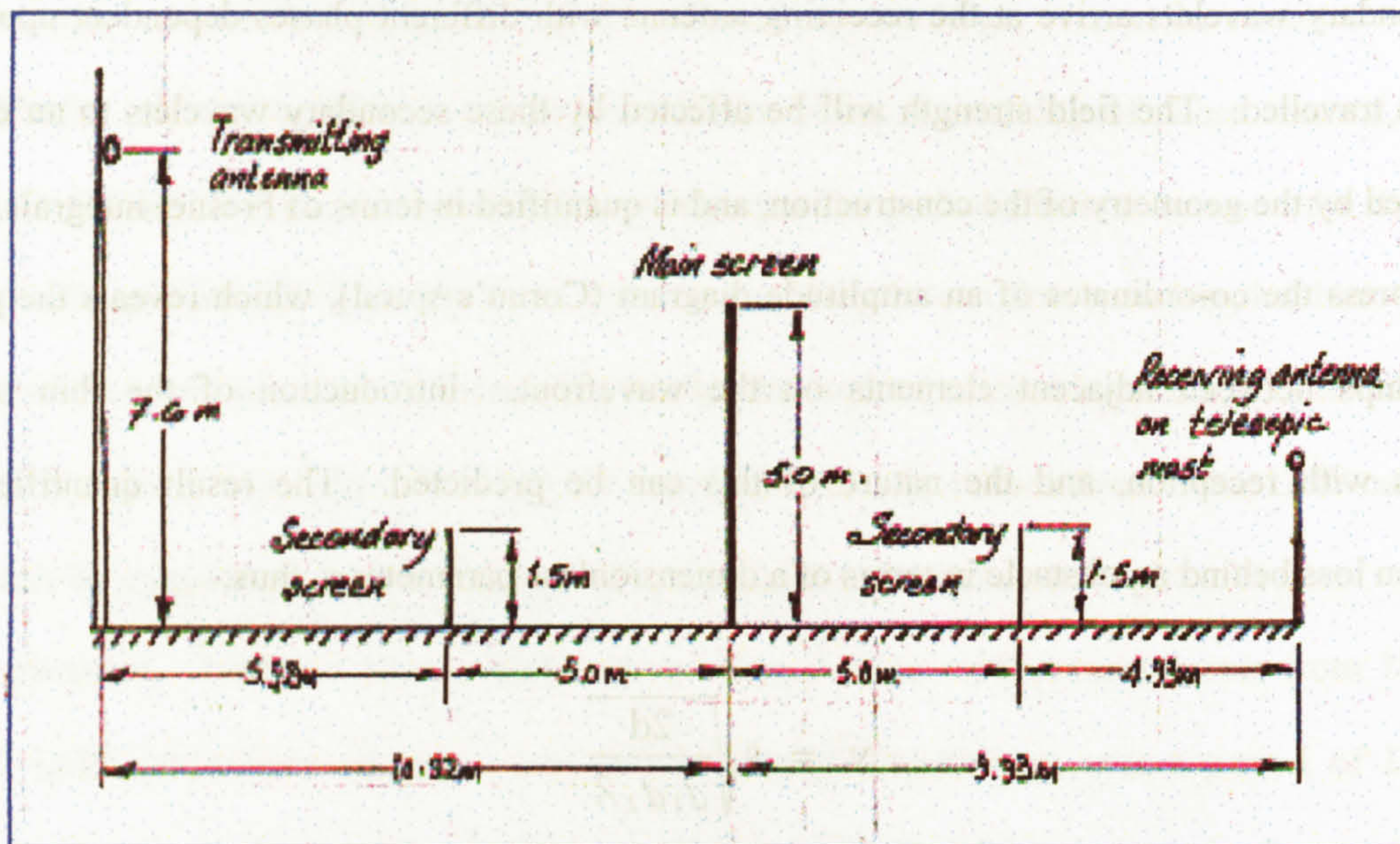


FIGURE 15
LAYOUT OF DIFFRACTION SCREEN CALIBRATION SYSTEM

The height of the receiving antenna was adjusted to record the field strength fluctuations

3.3.3. The Complications of "Real" Terrain.

The calibration methods described above provide simple examples of field strength prediction, applying optical ray theory over very short paths. The geometry of the path can be defined, and adequate results are achieved. However, the problems of "real" terrain, i.e., with the terminating antennas separated by all types of ground surface, are obviously much more challenging. The calculations of the free space, plane- and smooth-earth reflection and diffraction losses become

very complicated, and there is the additional confusion of ground cover. It is important to note, however, that at this stage of the discussion it is still assumed that the signal is only affected by the geometry of the path, which remains constant, i.e., it does not vary with time. Variations in the nature of the medium above the ground are not yet considered.

The extension of the basic ray theory to deal with all types of profiles, often including several diffraction edges, resulted in multiple integrals which were difficult to handle manually. Furthermore, the work to translate map data into ground profiles was long and tedious, and the precision of the definition of the terrain influenced both the complexity and accuracy of the calculation. First attempts, therefore, initiated before the widespread availability of computers and terrain databases, were designed to retain the relatively simple geometric methods whilst using uncomplicated models of the terrain. They limited the requirements for terrain data by confining the demand to seemingly important parts of the profile which obstructed the line-of-sight path, and simplified the calculation. Three classic examples are outlined here which illustrate this approach. As with the calibration technique described above, in each case they presumed the diffraction edges were thin, so that the approaching wavefront was not modified by their presence. These methods were developed by Bullington in 1947^(3.8), by Epstein and Peterson in 1953^(3.9), and by Deygout in 1966^(3.10).

The basic geometrical construction of all three can be described by considering the Bullington technique, shown in Figure 16. This required the construction of a single virtual knife edge D by extending and intercepting at X the horizon lines from the transmitting and receiving antennas (T) and (R). This edge is then used to predict the attenuation loss. Examination showed that the technique generally underestimated diffraction loss, the errors being least at low frequencies, i.e., below 100 MHz.

In the Epstein/Peterson construction, the diffraction losses over the individual edges were calculated separately and their values added to produce the total attenuation. Thus, referring to

Figure 16, the loss over edge A for the propagation path between T and edge B is calculated initially, assuming the receiver to be at B. The transmitter is then assumed to be at edge A, the path extended to edge C, and the loss of edge B is calculated. Finally the transmitter is assumed to be sited at edge B, and with the receiving antenna at R, the loss of edge C is predicted. The Epstein/Peterson construction has a sounder basis than the Bullington approach, because the calculated diffraction losses are related to actual edges, and it has some physical justification in that it observes, to some extent at least, the Huygen principle of wavefront creation. It is most accurate when the diffraction losses are high, that is, when the sequential receiving points are deep in the shadow of the preceding edge.

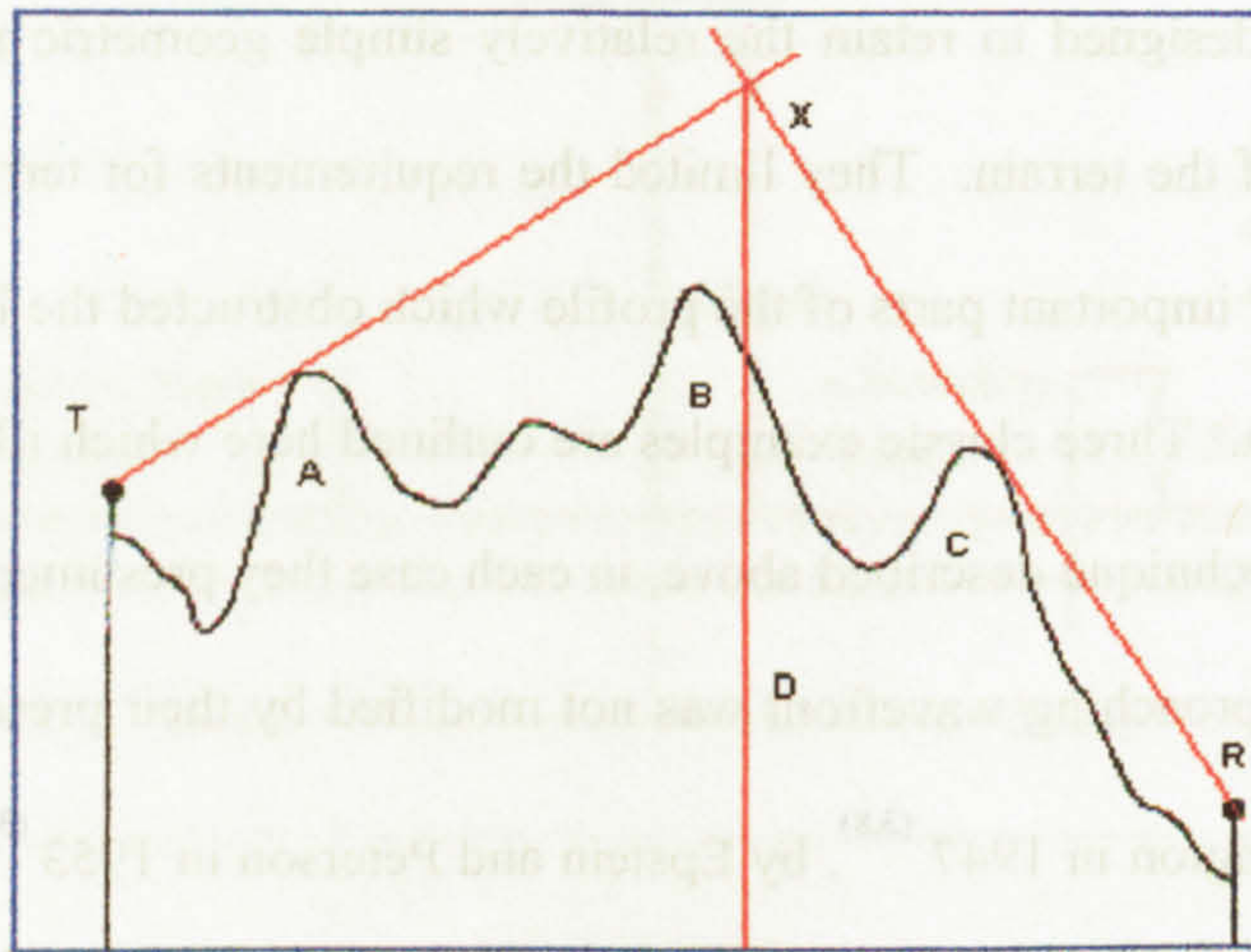


FIGURE 16
CONSTRUCTION OF THE BULLINGTON PREDICTION METHOD

Bullington method uniquely produces a virtual obstacle (x), whereas both Epstein/Peterson and Deygout techniques are based upon actual terrain features.

The Deygout method consists of calculating a loss for each diffraction edge in turn, assuming the remaining edges to be absent. The highest edge is treated initially (B in the Figure), and the loss of this is calculated, assuming the path to be terminated by T and R. This feature is used to divide the path in two, and the process is then repeated in the two halves as if the intervening edge B were a terminal.

For the purposes of calculating diffraction losses, these three methods use the knife-edge

representation which is quite unlike anything found in nature. In reality, of course, where the approaching wavefront encounters a hill having a rounded crest, specular reflections from the crest surface will perturb the free-space field for many wavelengths above the point of incidence. Similarly, reflections from the surface beyond the edge will influence the field strength at the distant receiver. Destructive interference will occur where phase reversal takes place at points between the crests.

A rigorous solution for the field diffracted over multiple terrain edges has always been a formidable mathematical problem, but a fourth method introduced in the early Sixties^(3.11) sought such an approach, at least for a path containing two diffractions. The field strengths at points along the wavefront above the second obstacle were calculated using normal Fresnel diffraction theory, by integrating the wavefront above the first edge. Each point on the wavefront above the second obstacle was then regarded as a Huygens source, and the total field strength at the receiver found by summing the contributions from all of them. The calculation for two edges thus involved a double integral. The process was complicated, although it was condensed by the originators who calculated losses for a wide range of variables. Thus application of the method involved reference to a collection of formulae and a series of curves. Although limited in its use by this approach, it was a technique in which the only approximations made were those normally encountered in Fresnel diffraction theory, and it was subsequently extended to deal with three edges. A somewhat similar method based upon measurements was also published in Japan^(3.12, 3.13).

The arrival of computers and terrain/ground cover databases transformed the scene, and it is unnecessary here to probe into the features of the basic models further than to report on their early accuracy. The author used the four methods to make predictions for comparison with 1,000 reliable measurements, involving propagation paths up to 50 km in length. The terrain covered by the results was gently undulating, and a small proportion of the receiving sites selected were affected by ground cover. The comparisons are shown in Table 12, which also includes predictions made with the Recommendation 370 method described earlier. It will be seen that the

four methods produced over-estimates of the field strength, and examination of the details revealed that the errors were greatest in the case of the diffracted paths, generally under-estimating the attenuation. This became very obvious after examining a number of paths for which field strength had been measured at intervals along their lengths. In contrast, the Recommendation 370 predictions produced a good mean result, although the distribution was large.

METHOD	MEAN ERROR (dB)	STANDARD DEVIATION (dB)
Bullington	12.5	11.2
Epstein/Peterson	9.6	13.5
Deygout	6.8	10.7
Millington	7.3	11.4
Recommendation 370/7	-1.8	12.7

TABLE 12
COMPARISON OF RATIO PREDICTION/MEASUREMENT

Largely on the evidence of results obtained using the two earliest models, the approach was modified in the USA using corrections based upon the assumption that the knife edge should be replaced by a parabolic cylinder^(3.14), and this opened up a new generation of prediction programs. These included results from research in the USA covering general communication activities^(3.15, 3.16, 3.17), and some interesting studies in Japan during the development of the VHF/UHF land mobile radio service^(2.26). Notably, the projects in the USA considered not only relatively short-range propagation, but also took account of refraction in the earth's atmosphere on longer paths - an important factor for the future development of the spectrum because it facilitated the prediction of the effects of unwanted interfering signals. Their main prediction program was eventually developed to become the Terrain-Integrated Rough-Earth Model (TIREM), used for many years in the USA after an extensive programme of modifications to compute point-to-point communication links at frequencies between 20 MHz and 20 GHz^(3.18).

It is relevant to note two applications of the optical approach to prediction that were carried out by the BBC in the early Sixties. These involved the use of light sources in conjunction with models of

the terrain. The first of these was an ambitious project in which service areas were predicted by photographing a three-dimensional map, illuminated by a small medical lamp of the type used in bronchoscopy, positioned at points representing transmitting antennae^(3.19). Mounted on a small motor, with the axis of the filament adjusted to be coincident with the camera lens' axis, the lamp was continuously rotated during exposure to smooth out the variations in intensity produced by the filament image and any irregularities in the glass of the envelope. The three-dimensional map used in the original experiment was made of bonded fibreglass, constructed on a spherical base of 2.74 m radius. The horizontal scale was 1 : 250,000, with the vertical scale exaggerated by a factor of 12 to emphasize topographical detail. Unfortunately the shadows resulting from the arrangement were so deep that they were below the threshold of sensitivity of the photographic emulsion; similarly, areas illuminated by the lamp were grossly overexposed. The contrast range was influenced by the short wavelengths of light and by the vertical scale of the map. However, experience of similar attempts described in an earlier but aborted German project^(3.20) was helpful, and the method was modified to predict the coverage of 17 planned UHF transmitting stations. It was hoped that the approach would be entirely objective, removing much of the subjective analysis which took place with other forms of prediction, but this was not achieved. Amongst many problems, serious flaws in the map, which was never intended for such minute investigation, raised justifiable doubts regarding the accuracy of the end result. Nevertheless, the method was promising, and it is likely that further investment would have produced a more reliable system.

The second optical approach pursued by the BBC^(3.21) concentrated on the examination of diffraction. Losses caused by large obstacles were examined both theoretically and by optical experiments using a laser source and idealized models. A helium gas laser operating at a wavelength of 632.8 nm was adjusted to emit a single-mode narrow beam of plane-polarized light. Polished aluminium cylinders were used to simulate hill profiles, and with a wavelength scaling of the order of 10^6 : 1, a rounded hill with an effective radius of curvature of 5 km was simulated by a cylinder of radius 5 mm. Surface roughness was simulated using wrappings of various grades of abrasive paper. This experiment produced much information concerning the influence of the shape

of diffracting edges, and although some of its conclusions were in conflict with measured observations, notably those concerning polarization differences, it provided some valuable evidence for the subsequent development of the BBC prediction program, described later.

Research in non-broadcasting organizations into prediction over "real" terrain for point-to-point systems continued to examine the mathematical development of optical theories, but the growth of point-to-area services, which included broadcasting and mobile radio, demanded a more pragmatic approach. To some extent this is illustrated by the Japanese work previously referenced ^(2.26), which adapted some of the totally empirical techniques employed in Recommendation 370, whilst introducing new ideas derived from the theoretical background for dealing with detailed terrain and ground cover features.

Almost invariably, national developments were based on research carried out by the countries concerned, and used local measurements as evidence. As mentioned before, an almost certain outcome was that the models proved to be most accurate when used on work within their country of origin. For this reason it proved virtually impossible to achieve international agreement on any of these new predictions for broadcast planning, which remained firmly based upon the coarse but established ITU Recommendation 370, augmented locally by detailed national techniques to make the most of those assignments. Occasionally, however, some improvements emerged from co-operative work within international organizations, and produced contributions to ITU recommendations. A major example of this type of output is Recommendation ITU-R P.452-7 ^(3.22). Originally relating to an ITU Report dealing with point-to-point propagation ^(3.23), the groundwork for the transformation of this into a full prediction program was carried out by COST Project 210, conducted between 1984 and 1990 using specialists from ten European countries ^(2.11). Unfortunately, the results came too late to satisfy the demands for broadcasting. In any case, the project concentrated on frequencies above those used initially by the broadcasters, although in its studies the COST group used some of the measurements obtained by the broadcasting organizations. International cooperation on the development of Recommendation P.452 was

continuing at the time of writing.

Over the years many new predictions emerged, each satisfying national demands. Seeing a lucrative place in an emerging market, some have been developed or “adapted” by commercial organizations, and offered as a service. Usually these methods are confidential, and it is difficult to establish their accuracy, although it is clear that empiricism has increasingly influenced these developments. Often claiming strong theoretical foundations, the parameters of many have been very substantially adjusted to satisfy measured evidence, and the theory provides only a sequence for the series of operations through which the prediction passes. This can be illustrated by describing the development of one model - that developed by BBC Research Department - which remained in use over a period of more than 30 years, and which has been the basis for some of the programs which have been developed by other authorities.

3.3.4. The Impact of Empiricism - the BBC Prediction Program

Before describing the introduction and development of the BBC program, it is useful to reference another model which opened up the vital subject of terrain databases in the UK, and the means whereby this valuable information could be modelled for the purposes of prediction. It was a method which took edge diffraction into account, and was intended for land mobile radio applications^(3.24). Some information concerning the technique used to produce the terrain database has already been given in Chapter 2^(2.23), but it is necessary here to consider in more detail the ways in which these data were used to reproduce a ground profile, because this process has an important effect upon the accuracy of the prediction.

As described earlier, the terrain data were originally derived for a matrix of squares, each having 0.5 km sides, covering the land masses of the UK. The technique emphasized the ruggedness of the terrain, originally regarded as a desirable feature for planning purposes because the prediction tended to underestimate the coverage and overestimate the interfering signal. The database stored a

representative height for each square, so it was not easy to increase the precision of the database, a requirement which is desirable if there is need to explore the terrain at a precise point, perhaps a diffraction edge. Had the information recorded the heights at precise x : y coordinates, then this would have been possible. Nevertheless, whilst the database may at this distance now be regarded as crude, at the time it represented a giant leap forward in the attempts to achieve greater precision in prediction. The base data from which the heights were derived (Ordnance Survey 1 : 10,000 scale maps) contain negligible error - the spot heights and 10 m. contour lines are quoted by the publishers as having errors of ± 0.5 and ± 2.0 m. respectively. Several methods of data interpolation for the construction of ground profiles were considered, and that chosen provided profiles defined by heights with uniform horizontal separation along each path.

The accuracy of the method was determined during the course of this project by comparing derived heights for a large number of selected locations with actual terrain heights for those points. Wherever possible, spot heights were chosen for these checks, as these give the most precise height information available. The results of this comparison are shown in Table 13.

Nature of Terrain	Sample Size	Mean Difference (metres)	Standard Deviation (metres)
Flat	1630	0.5	7.7
Gently Undulating	1820	1.9	17.2
Hilly	1524	0.8	16.7
Mountainous	3256	0.5	16.8

TABLE 13
TERRAIN HEIGHTS

The table shows the distribution of the differences between the terrain heights derived from the database and those defined by the Ordnance Survey

To be expected, the error as measured by the standard deviation is greatest in hilly and mountainous areas, although there is relatively little difference between the gently undulating terrain of the Home Counties and the mountainous areas of Wales. The mean error is small, and reveals no serious bias in the method. However, the worst errors of interpolation with this database

were likely to occur at the upper and lower limits of the height range covered, due to the method of base data definition, and the technique of profile generation. This means that the greatest discrepancies appeared at potential diffraction edges, or often at the points selected for reception - unfortunately both important for prediction purposes.

Data Spacing (km)	Prediction/Measurement Mean Error (dB)	Prediction/Measurement Standard Deviation (dB)
0.02	-4.4	4.1
0.05	-4	4
0.5	-1.9	7.4
1	-1.3	10.7
2.5	1	12.5

TABLE 14
THE INFLUENCE OF TERRAIN DENSITY
UPON PREDICTION ACCURACY

The distributions of the ratio prediction/measurement compared using different terrain databases. The BBC prediction based on the 0.5 km data was used throughout

The development of the BBC prediction was based upon the 0.5 km database, but at an early stage the relationship between precision and height data density was questioned. The results in Table 14 give some indication, but do not answer the query. In the Table the value of increased terrain definition has been forecast for a relatively small area of Southern England using prediction results from the program. The 20 m. height data were obtained from an early satellite experiment, and the 50 m. base was provided by the Ordnance Survey. In both cases the values stored were assessments of the actual altitudes at precise grid points. Both the 1.0 and 2.5 km bases were derived by storing the maximum height within each square. The prediction method used, based upon the 0.5 km database, displayed a bias of -1.9 dB. The accuracy apparently achieved by the use of greater detail in the existing program can be seen from the Table, but obviously any conclusions will be affected by the fact that parameters in the prediction had been optimized on the evidence of the 0.5 km database. Had greater detail been available during development, attempts would have been made to modify and improve the model.

Development of the BBC program started in 1964 when its Research Department acquired a digital computer. This was used to carry out field strength predictions using the Recommendation 370 technique, adapting a program previously used at the 1961 Stockholm Conference. However, the need for improvement to satisfy national requirements was recognized, and a revised model was devised, based upon UK measurements ^(3.25). This was a radical departure from the international method, but still relied upon somewhat crude field strength/distance curves, the absence of detailed terrain data obstructing a more fundamental approach. Further modifications to this method were introduced later ^(3.26), but the acquisition of the 0.5 km terrain database in 1971 opened the way for a completely new prediction, which could take account of the unique features of each path profile. The detailed contents of the program, and the mathematical treatments leading to the formulae used in the prediction, are described in a BBC manual ^(1.81). The program was eventually developed to deal with all broadcasting frequencies between LF and UHF, but for the purposes of this thesis the following outline description is confined to that part dealing with the UHF band.

The calculation was based upon the assumption of the reception of free-space field in the absence of obstacles, but, as will be seen later, took account of the temporal variation which occurred with distance. Diffraction loss was calculated using the Deygout method, initially adopted because it could be extended to a path with any number of edges, unlike that of the second preference - the double integral of Millington - which became increasingly complex as the number of edges increased beyond two. However, in practice the calculation was limited to three diffractions, although each of these could be a closely spaced group, referred to as running edges.

In effect the profile was constructed using the "stretched string" principle, as shown in Figure 17. The vertical lines in the figure represent the distance/height sequence from which the profile is reconstructed. Using the Deygout method, edge B is first selected for diffraction calculation, and subdivides the propagation path into two. In this particular case, edge B forms a so-called "running edge", a series of adjacent edges each of which would be touched by the imaginary stretched string. In the early versions of the program, the calculation for this edge was performed assuming a virtual

edge, i.e., as in the Bullington construction. The program then went on to undertake a truncated Deygout calculation, predicting losses for the remaining two edges A and C, and combining the total of the three to produce the overall path attenuation. Later, however, the terrain database offered the opportunity to interpret the surface, particularly running edges, using a range of simple geometric shapes, notably rounded- or wedged-shaped, which more realistically represented the actual situation.

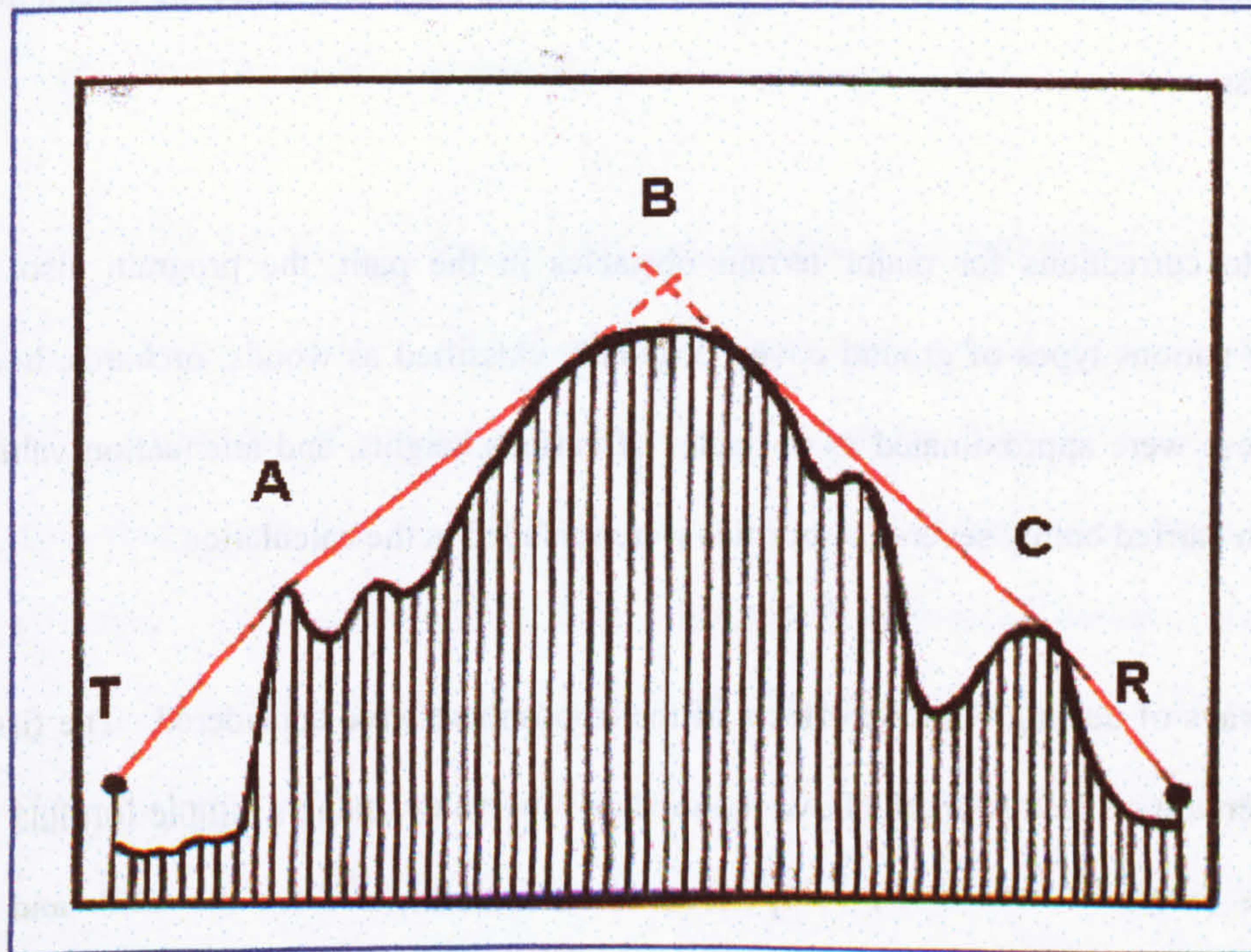


FIGURE 17
PROFILE ANALYSIS

The process assumes a string is stretched between the antennas T and R. In the early prediction, a virtual height shown by the dashed lines at B was produced, but later this interpretation was improved

After further research into diffraction theory over the type of rounded edges which appear in nature, it was concluded that some of the theoretical techniques, often demanding quite complex mathematics, could not be justified in a situation where the edge was defined by the interpolation of a coarse matrix of terrain heights. A pragmatic approach was adopted, originally proposed by Van der Pol and Bremmer^(3.27, 3.28), in which the result appears in the form of a residue series, created by analysing the exact situation in increasing detail. However, a further simplification^(3.29)

which limited the calculation of the residue series, was adapted for the BBC program, accepting the various restrictions which this approximation introduced (in fact the approach was identical to that used in the Longley and Rice program^(3.17)).

Diffraction over a wedge was treated as a modified Fresnel diffraction problem, using a four-ray technique originally devised for use at lower frequencies, the additional rays arising through ground reflections being associated with images of the source and receiver^(3.30). The presence of these rays influenced the wavefront created at the crest of the edge, and hence the calculation of the diffraction loss.

In addition to corrections for major terrain obstacles in the path, the program also included provision for various types of ground cover, originally classified as woods, orchards, houses and factories. These were approximated as obstacles of various heights, and attenuation values based upon research carried out by several authorities were included in the calculation.

Two major ways of dealing with the effects of the troposphere were considered. The first was to define the increase of field strength above the median time value, using a simple formula as in the Longley-Rice program. However, comparison of measurements from the USA and the UK confirmed the relatively turbulent maritime situation of the British Isles compared with the large land mass of the USA created quite different tropospheric conditions. Thus the relatively simple solution had to be rejected in favour of an alternative approach, based upon the regional temporal distributions recorded in UK experiments.

As discussed before, most temporal changes in VHF/UHF signals over the longer distances were attributed to refractive index variations in the troposphere. Departures from the neutral condition affect refraction, and the general influence may be quantified by the use of an effective earth radius a_e such that:

$$a_e = ka$$

where a is the actual earth radius. By relating the observed temporal distribution of measurements made over long distances, adjustments can be made in the value of k to take account of enhanced propagation during certain tropospheric conditions, and this was the basis of the technique used to predict time variability in the BBC program. In the case of the UHF prediction, results from a number of long-distance recording experiments were used to specify the program's parameters, based on measurement levels exceeded for 50%, 5% and 1% time. Thus having derived the ground profile from the terrain database, the curvature of this could be adjusted to represent conditions for certain percentages of time, and the diffraction loss calculation performed for a profile modified to simulate the effects of abnormal propagation.

From the foregoing it will be seen that the BBC program had a theoretical basis, indeed the report describing its original contents ^(1.81) provided a most impressive list of references, revealing the extent of the research into the subject. However, empiricism has been extensively employed to rectify imperfections revealed in the application of these theories. Theoretical components, and the parameters defining their contribution, were optimised following iterative processing by comparison with measurements. This process continued throughout the history of the prediction as new results became available. In common with other similar programs, it is a compromise between a very complex analysis of electromagnetic theory, and measurement. Nevertheless, for many years it provided a rational and reasonably objective approach to prediction. Table 15 shows a series of comparisons made using Recommendation 370 and the BBC prediction techniques for the VHF/UHF broadcasting bands, using the measurements' database described in Chapter 2. These results were obtained in 1996 by the author and used the program then in existence. It must be mentioned that the Table does not show results for short range paths, i.e., < 10 km, because the CCIR prediction in the form tested here did not include provision for these distances. Inclusion of these short paths in the BBC results improves the overall prediction error, for example, at UHF, the mean error reduces from - 3.1 dB to -1.7 dB. Closer examination shows that the BBC method achieves maximum precision for paths < 50 km. in length, there being two reasons for this. Firstly, much more data for the short paths has been input for optimisation since the introduction of the program. Secondly, discussed throughout this thesis, errors of measurement interpretation were

much greater at the longer distances. If the overall comparison is judged on the mean figures, the CCIR method appears to produce better results, but objectivity, the better performance at shorter ranges, and lower standard deviations, especially at UHF, were advantages of the BBC method.

Frequency Band	Sample Size	CCIR P/M Mean (dB)	CCIR S.D. (dB)	BBC P/M Mean (dB)	BBC S.D. (dB)
I	5833	1.4	7.1	3.9	7.0
II	7013	-3.9	8.3	1.3	6.8
III	7292	1.1	8.5	3.1	7.4
All VHF	20138	-0.6	8.4	2.7	7.1
IV	6385	3.4	12.6	-2	9.7
V	5984	-1.3	11.7	-4.2	9.3
All UHF	12369	1.1	12.4	-3.1	9.6

TABLE 15

**COMPARISONS OF CCIR AND BBC
PREDICTIONS WITH MEASUREMENTS**

3.4. The International Negotiations 1991 - 1997

As mentioned in 2.6., during the second phase of the research project from 1991 to 1997 the relevant ITU/CCIR Study Group was concerned with an investigation into the possibility of replacing Recommendation 370. As a contribution to this work, the BBC offered to the Group a method which was originally suggested in the research report describing their activities during the period 1984 - 1991 ^(2.24). With the help of a computer specialist, Mr. R. W. Lee, a program known as PATHCAT was produced by the author, which after discussion within the group was accepted, and in 1997 became a CCIR Recommendation ^(3.31). However, before outlining this method (and its short subsequent history), it is necessary to report some preliminaries.

Much emphasis has been placed at points in the previous text on the correct interpretation of measurements used as evidence, and it was agreed at the start of the international project in 1991

that a reliable data bank of results drawn from as many authorities as possible was essential. This would be used to examine the precision of prediction methods considered by the group, and avoid the discrepancies so often obvious in the past. It would be an international version of the U.K. data bank described in Chapter 2, but would include temporal as well as spatial measurements. It would cover the spectrum from 30 MHz to 3.0 GHz. The measurements were subsequently recorded using the format prescribed by an ITU Recommendation ^(3.32). In its introduction the latter states that data banks “must contain data that are of an adequate standard, and be widely accepted as the source material on which to conduct testing”.

Transmitter	Receiver
Transmitter name	Receiver name
Designation of emission	Country
Country	Latitude
Latitude	Longitude
Longitude	Ground height
Ground height	Antenna height
Antenna height	Antenna directivity
Polarization	Receiving environment
Power in horizontal plane	
Power in vertical plane	
Frequency	
Path Details	Meteorology
Path length	Rain zone of transmitter
Type of path	Rain zone of receiver
Profile information	Min. monthly surface refractivity
	Av. annual sea-level refractivity
	Other met. data
Experiment Details	Measurement Data
Start date of experiment	Tabulation field strength v. % total time
End date	do. for worst month
Daily start time	
Daily end time	
Total measurement time	
Type of recording	

TABLE 16
CONTENTS OF ITU/CCIR DATA SHEET (Rec. P.311-7)

**Experimental record intended to report variation of
signal with time**

Measurements were separated into four sections, the first two dealing with terrestrial land mobile wideband and narrowband statistics, the second pair containing details of broadcasting signal level variations with time and with location. As an example, Table 16 shows the broad contents of the

data sheet for one measurement describing the variation of a signal with time. This specified the locations and operational characteristics of the transmitter and receiver. Provision was made for ground profile definition, and any meteorological information which might assist with the analysis of upper air conditions.

Over a period of four years a substantial quantity of data was processed, and the size of the international data bank by 1995 is shown in Table 17, which lists the principal contributing countries, together with the number of measurements. In addition to those listed, 55 other countries gave small contributions totalling 36 spatial and 320 temporal measurements. Not surprisingly, virtually none of the measurements received from abroad complied with the reception standards which were used to analyse the UK data, and wherever possible, temporal variation was converted to the form of statistics describing annual results. Similarly, as far as possible, spatial results were recorded as mean values for measurements within 100 m. squares. Fortunately, under the administrative mechanism set up by the ITU, provision was made to add information, as and when it became available, and there was considerable co-operation during this phase. The database facility proved to be a important international asset in the work described here ^(3.33).

COUNTRY	NUMBER OF MEASUREMENTS	
	Spatial	Temporal
Arab Emirates		129
Australia	216	12
Canada		53
Finland		239
France	71	33
Germany	12314	72
Ireland	199	43
Japan	234	107
Netherlands	73	68
Switzerland	1247	4
UK	80866	2016
USA	9524	379

TABLE 17
MEASUREMENTS FROM COUNTRIES
CONTRIBUTING TO THE 1991-1997 STUDY

It may be argued that the dominance of UK results would bias the study, but this is not so. In

general, the investigations confirmed that the factors which determine spatial change in field strength were universal - there was no significant regional influence. Local changes in ground cover, e.g., building styles, certainly affected diffraction losses, but did not demand fundamentally different prediction techniques. On the other hand, temporal changes were influenced by regional conditions, and for this reason contributions of measurements from countries spread around the world provided valuable comparisons with the conclusions already reached following the highly detailed examination of the UK results.

In addition to the data described above, a large number of separate results from broadcasting archives was also processed for this phase. These measurements provided additional detail such as information about the effects of antenna height changes and polarization, but because of their irregular format they were not included in the international database.

However, although an impressive measurements' database was built up, few national prediction programs were offered for examination. Furthermore, examination of their contents revealed the same difficulties which were becoming obvious with the contemporary BBC program - the use of many empirical corrections to adjust interdependent parameters affected the theoretical bases to the point where using the latter as justification became suspect. Even where individual features of optical theory were applied in impressive complexity, the difficulties of providing the information needed to define the propagation paths in sufficient detail were serious. Also, as reported before, the empirical corrections were invariably based upon regional results. Attempts to achieve international agreement using the latest measurements' data bank were unsuccessful in the time available.

Failure to agree that any one of the programs available could be recommended for international development prompted the suggestion that the almost totally empirical PATHCAT approach should be selected for closer study. It was decided that a single basic prediction would be devised using the international measurements' database, and that a sequence of operations would be followed, based upon successive refinement of the definition of the propagation path. Thus as more

information describing each path became available, the precision could be progressively improved.

The sequence of the prediction was as follows:-

- the first phase produced the basic field strength results -- determined by the length and nature of the propagation path, and the effect of tropospheric variations upon reception,
- the second phase -- measuring the "exposure" or prominence of the terminal antenna in respect of its relationship to local terrain in the path, and the application of the TCA correction,
- the third phase -- taking account of the environment of the antennas, and their height with respect to immediate ground cover in the path.

The objective was the prediction of the field strength time and location distributions within a 100 m. square, with results showing the means and standard deviations for receiving antennas 10 m. a.g.l. The terrain within the square was assumed to be flat, i.e., the ground undulations did not exceed 10 m, and it was also devoid of ground cover - in terms of the early CCIR definitions such an area was described as "rural". Unfortunately, the state of the measurement analysis in the early Nineties precluded such precise definition, so the results provided by the first PATHCAT program did not reveal distributions for defined areas. However, the international measurement database was a considerable improvement on that used to construct Recommendation 370, and the results revealed this progress.

Field strength/distance curves were regarded by the group as the simplest and most useful form of prediction for the task in hand, and this form of presentation was used for the first phase of the prediction. Thus, an overland propagation path was placed into one of three categories:-

- Category 0 - no terrain obstruction, i.e., line of sight
- Category 1 - one terrain obstruction
- Category 2 - more than one terrain obstruction

These were coarse categories, and in particular the single allocation of "line-of-sight" conceals the effects of changing the heights of the terminating antennas. However, in the immediate interests of simplicity and on the evidence of the results this was initially accepted.

Separate provision was made for oversea paths, although in the early version the technique for dealing with mixed land/sea conditions was inadequately defined. There was also some differentiation between transmission over "cold" and "warm" seas, obtained from results from the North Sea and Mediterranean Sea regions, but again the evidence was sparse in the early stages — there was little time to absorb the contents of the measurements' database. Sets of curves were produced for both land and sea categories, showing conditions for 50%, 10%, 1.0% and 0.1% time. Thus given the path category and distance, the 50% location field strengths and the temporal distribution were defined by the relevant decay curves.

In the second phase of the prediction, the effect of terrain within 5.0 km of the transmitting and receiving sites was taken into account by using a modified TCA correction, an approach similar to that previously adopted for Recommendation 370.

The third phase dealt with the influence of local ground cover. The effects of four types of ground cover were determined from the measurements - rural, suburban, urban and dense urban, and corrections were introduced for these. This adjustment also included provision for the height of the antenna in relation to the ground cover. Additionally, for mobile services, some information was provided concerning the improvement in reception in built-up areas when the direction of the propagation path was approximately aligned with that of the route through the ground cover. Similarly, the advantages under certain circumstances of using vertical polarization for reception at low (i.e., less than 1.5 m. a.g.l.) heights were also quantified.

The early PATHCAT method was far from perfect. It revealed a lot of new information, and it took account of a considerable quantity of measurements from world-wide sources, although as usual under pressure, the research had to be limited. Inevitably it met opposition from those who

felt a different approach should have been adopted, including some who were reluctant for political rather than technical reasons to abandon Recommendation 370. There was concern that the edifice upon which all the previous plans had been constructed was about to be destroyed. A more reasoned argument was that the proposal was simply substituting one empirical method for another, and with modern resources a more scientific approach should have been pursued. This was true, but consensus could not be agreed solely on the basis of scientific arguments. Nevertheless, on the evidence available at the time of its presentation, it offered improvements over earlier methods. Table 18 shows a comparison of the results obtained using four prediction models which were examined as part of the work of the international group (note the ITS program used here is that mentioned earlier and described in reference 3.18). For obvious reasons, the PATHCAT program received the most searching examination.

METHOD	FREQUENCY (MHz)	SAMPLE SIZE	SOURCE	PREDNMEAST (dB)	STAND. DEVN. (dB)	PATH LENGTHS (km)
ITS	320 - 910	100+	USA	2.5	4.9	<80 (L.O.S.)
ITS	320 - 910	100+	USA	4.3	13.3	<80 (Diffracted)
ITS	653	3400	Germany	2.4	14.5	9 - 100
ITS	653	1400	Germany	1.2	15	9 - 100
Rec.370	40 - 220	20138	UK	-0.6	8.4	<130
Rec.370	470 - 860	12369	UK	1.1	12.4	<130
Rec.370	40 - 220	574	UK	-1.3	7.3	50 - 950
Rec.370	470 - 860	354	UK	-1.9	10.7	50 - 950
BBC	40 - 220	20138	UK	2.7	7.1	<130
BBC	470 - 860	18116	UK	-1.7	10.3	<130
PATHCAT	40 - 220	21078	UK	-1.2	8.1	<130
PATHCAT	470 - 860	18117	UK	4	11.5	<130
PATHCAT	40 - 220	517	UK	-0.2	7.1	50 - 950
PATHCAT	470 - 860	345	UK	3.6	10.4	50 - 950
PATHCAT	40 - 860	1381	EBU	0.3	8.5	<100
PATHCAT	40 - 950	635	USA	1.6	9.2	<100
PATHCAT	40 - 220	100	Brazil	2.1	9	<100
PATHCAT	90 - 750	100	Australia	1.4	8.7	<100
PATHCAT	90 - 100	46	Hong Kong	3.5	11.2	1 - 15

TABLE 18
COMPARISONS OF PREDICTIONS
WITH MEASUREMENTS

Anticipating many immediate objections to the PATHCAT method as a total replacement for Recommendation 370, particularly from countries not represented in the specialist examination that had taken place, a strategy was adopted by the ITU. The new recommendation was published as a

technique initially suitable for prediction in the frequency range 1.0 to 3.0 GHz^(3.31). It thus complemented the older Recommendation, which had an upper limit of 1.0 GHz. This was an unfortunate manoeuvre for a number of reasons, not least because in carrying out the research into its development, less than 10% of the measurements used came from work at frequencies above 1.0 GHz. However, almost immediately attention was focused within the ITU on the greater problems of analogue/digital transmission conversion, and there was an urgent need for consensus on the method to be used for the international re-planning of the terrestrial networks below 1.0 GHz. It was inevitable that Recommendation 370 should again be pressed into service because it was the only internationally approved technique immediately available for dealing with the frequency range affected, and this was endorsed in the documents describing outline proposals for Europe^(1.102).

In retrospect, it is unfortunate that there was so little support for the efforts made spasmodically throughout the second half of the Twentieth century to improve the field strength prediction method that was at the heart of the international planning of the vast VHF/UHF broadcasting services. Some improvements were implemented, but many of the fundamental problems described in Chapter 2 remained. Several countries made use of the knowledge and experience they acquired in their national planning, but most of this never achieved international status. Many of the reasons for this were political, rather than scientific or technical, so it is not so surprising that international negotiations could become tedious and confused. One indefinable result was that the radio spectrum was inefficiently deployed, but more immediately important in 1997 was the likelihood that prediction features of this international planning machinery were now to be used for a major re-development, even though there were many reasons to doubt certain features. Notably, the UK was likely to be particularly affected, because as will be described later, its position as an island rendered its services particularly vulnerable to tropospheric interference from transmitters on the continental mainland. With this feature in prospect, and with the benefit of a substantial quantity of evidence concerning past research into the many subjects involved, the author started an independent review of the situation in 1997, centred on the development of field strength prediction. The next Chapter describes these activities.

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4. Recent Research for a New Prediction Method

4.1. Summary

This Chapter describes work undertaken by the author since 1997 to pursue the field strength prediction investigation. It was hoped this would lead to a realistic analysis of the UK analogue television coverage, so that proposals for digital replacement likely to emerge in the coming years could be thoroughly assessed. Work before 1997 had demonstrated that the existing measurement records and prediction techniques could not provide the detailed information needed. These had been the basis for the planning of the original network, but the end results had never been properly monitored, and public reaction to the technical quality of their reception was unclear. Planning techniques would be vital in the new situation in which digital services were to be added to the densely-packed frequency spectrum alongside the widely-used analogue transmissions. All sorts of promises were being made, could they be delivered?

The prediction process was re-examined in depth, using a very wide sample of measurements, including over 220 LDR experiments covering the frequency range from 41 to 774 MHz. In the absence of upper air data to research propagation conditions, important clues to tropospheric conditions were obtained using new information from the Meteorological Office. A detailed analysis of the surface weather reports exposed the influence of the various airstreams across the British Isles upon the dynamic structure of the lower troposphere. This led to an examination of the correlation between the airstreams and the incidence of abnormal propagation over a period of 30 years during which many of the LDR experiments took place. The results produced what is believed to be a more realistic analysis of the field strength recordings, and led eventually to a revised version of the PATHCAT prediction.

4.2. Distinction Between Spatial and Temporal Variation

In the development of the principal prediction methods used for broadcasting these two domains have been treated separately, i.e., it has been assumed that factors affecting the spatial changes could be isolated from those which caused fluctuations with time. Problems with this assumption have been described in previous chapters, therefore at the start of the work now described, more precise definitions were sought.

The case of spatial variation seemed relatively straightforward, and the previous base of a 100 m. square was retained, with the range of field strength within this area described as the "microscopic" distribution. In the basic state, the terrain within the square was flat, i.e., ground undulations did not exceed the height of the antenna (taken to be 10 m. a.g.l.), and it was free of ground cover. Further analysis of the measurements then deduced the effect of ground level and ground cover changes upon this distribution. To quantify spatial variation on a wider but still local scale, the individual 100 m. media of several contiguous 100 m. squares was defined as the "macroscopic" distribution. This extension confirmed the influence of local terrain changes on the overall path - usefully measured by the TCA - this was usually the cause of difference between the median values in adjacent 100 m. squares. Importantly, as will be described later, this also provided a link with the analysis of temporal variation.

The independent definition of temporal variation was more complicated. As described in Chapter 3, many of the LDR results had already been re-analyzed to reveal annual distributions, because within this period of time the full range of factors likely to influence propagation conditions would be exposed. This is true when the investigation is confined to the incidence of long-term periods of abnormal propagation, which are closely related to the movement of large air masses. However, the statistics of brief abnormality, e.g., rapid fluctuation of field strength, are also important - especially for digital transmission - and during these periods it was difficult to distinguish between temporal and spatial changes in the LDR experiments. This was a feature emphasized during the SVF tests, described later. Of course, these occur even at short ranges, when both terminating antennas are at fixed points and within line of sight of each other. Apart from movement at a "solid" reflection point, complex scattering of the clear-air component can be caused by rain, fog,

snow and hail (hydrometeors), a feature generally associated with transmissions above the VHF/UHF bands, i.e., > 3.0 GHz, although the effects have often been observed at the lower frequencies. Means of predicting the statistics of the variation caused by clear air effects on point-to-point paths have already been referenced^(2.9, 2.10), but because of their demands for detailed data they were unsuitable for point-to-area calculations.

Examples of the extent of temporal changes at short ranges are given in Table 19. This shows median values derived from about 1,400 experiments in temperate zones of the world intended to produce a line-of-sight field strength/distance curve up to a distance of 50 km. The results were obtained at flat, open receiving sites, and the duration of each measurement extended from a few hours up to 12 months, the average being just over four months. These experiments were intended to study sporadic features such as aircraft flutter and tidal fading, but also recorded the temporal variation in the absence of the feature under investigation. During these substantial "quiescent" periods, field strength as a function of time generally observed a normal distribution, and the limits of the distribution increased both with path length and frequency. For reference, the theoretical free-space field strength is shown in parentheses in the second column, which lists the median values derived from all the measurements used eventually to construct the basic curve. The Table shows differences between regional medians and the overall result, and endorses the earlier observation that spatial variation is materially unaffected by regional factors.

Distance (km)	Derived Field Strength dBuV/m	Distribution of Measurements dB					
		UK		N. America		Europe	
		median	σ	median	σ	median	σ
5	80 (93)	0.4	4.6	0	4.1	-0.2	4.7
10	74 (87)	-0.3	4.3	0.5	4.5	-0.2	4.7
20	66 (81)	-0.9	5.1	0.4	4.6	0.6	5.3
30	61 (77)	0.2	5.7	-0.1	5.5	0	5.9
40	57 (75)	0.7	6.4	-0.5	6	0	6.2
50	53 (73)	0.3	6.1	-0.5	6.4	0.3	6.8

TABLE 19
SHORT-RANGE UHF FIELD STRENGTH MEASUREMENTS
(RESULTS FOR 1.0 KW ERP)

Medians of all contributed measurements shown in second column, compared with theoretical free space values (in parentheses). Distributions show differences between regional and derived medians, and standard deviations of each contribution

Figure 18 gives further information concerning the influence of the upper air on slightly longer paths around but still within the radio horizon range^(4.1). These observations were relatively short term, occupying hours rather than months, and were an early attempt to use meteorological data to quantify temporal variation. In the Figure, 350 groups of measurements have been compared with predictions to produce prediction/measurement ratios. The interdecile ranges of these, shown by the vertical shaded bars, have been plotted against the surface pressure recorded at the time of measurement by local weather stations. The results show that when atmospheric pressure is low, the field strength is correspondingly low, and the prediction - derived from all measurements and hence representing "average" atmospheric conditions - is high. The situation is reversed when the pressure increases. Later work was to show the horizon range is a critical point which determines the extent and nature of temporal variation, but these early results demonstrated the influence of surface pressure upon field strength.

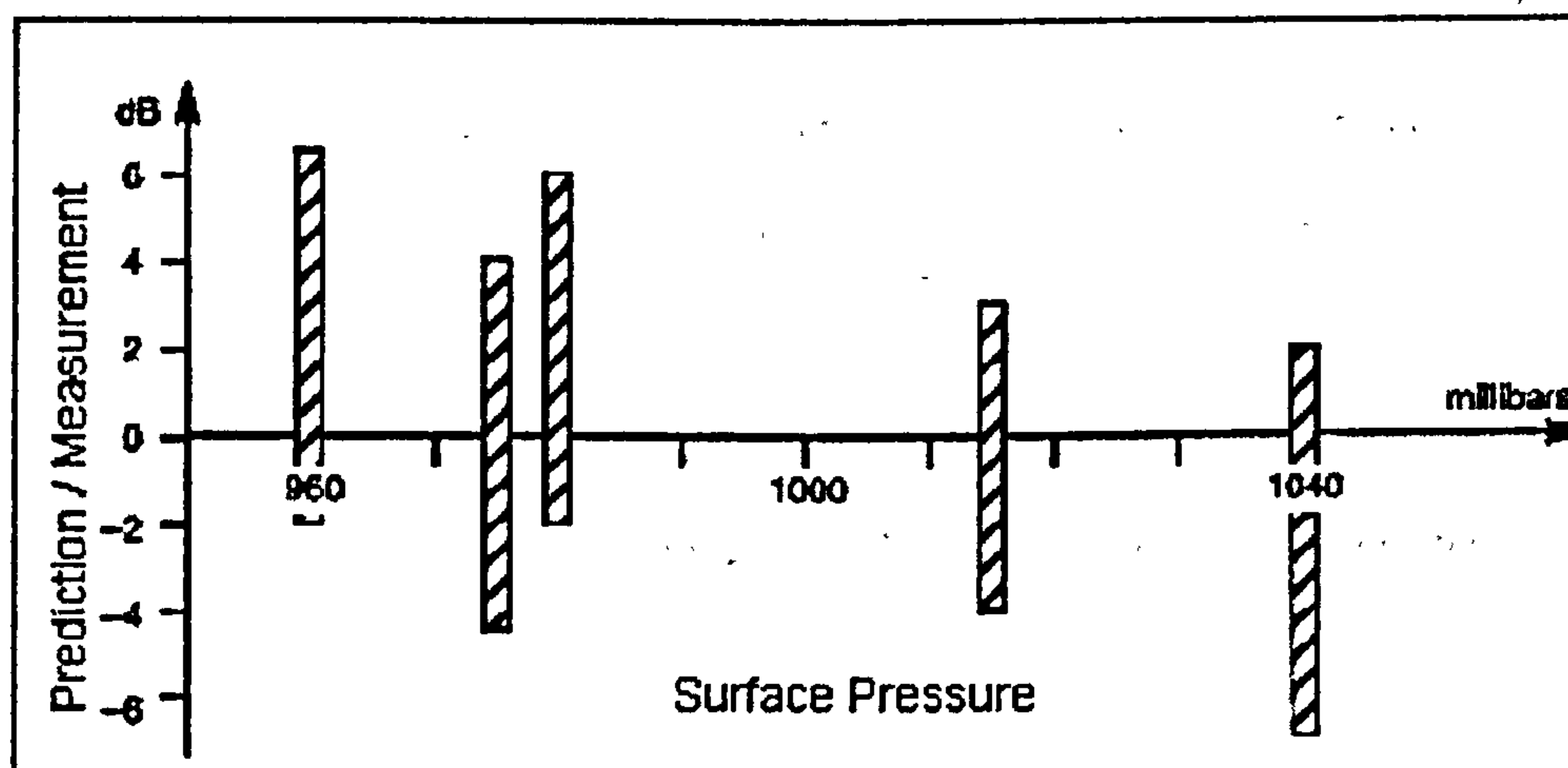


FIGURE 18
PREDICTION/MEASUREMENT RESULTS COMPARED
WITH SURFACE PRESSURE OBSERVATIONS

The distributions of the ratios predictions/measurements are related to the local surface pressures recorded at the time of the field strength measurements.

Figure 19 presents a conceptual interpretation of the variation of field strength with time, deduced from a great many experiments. For continuous measurements at receiving sites within the radio horizon of a transmitter, typically represented by curve A, the slope increases with the path length, and is generally normally distributed throughout its interdecile range. Its relationship to the

theoretical free-space value (E_0) depends upon the profile geometry and the clear air conditions.

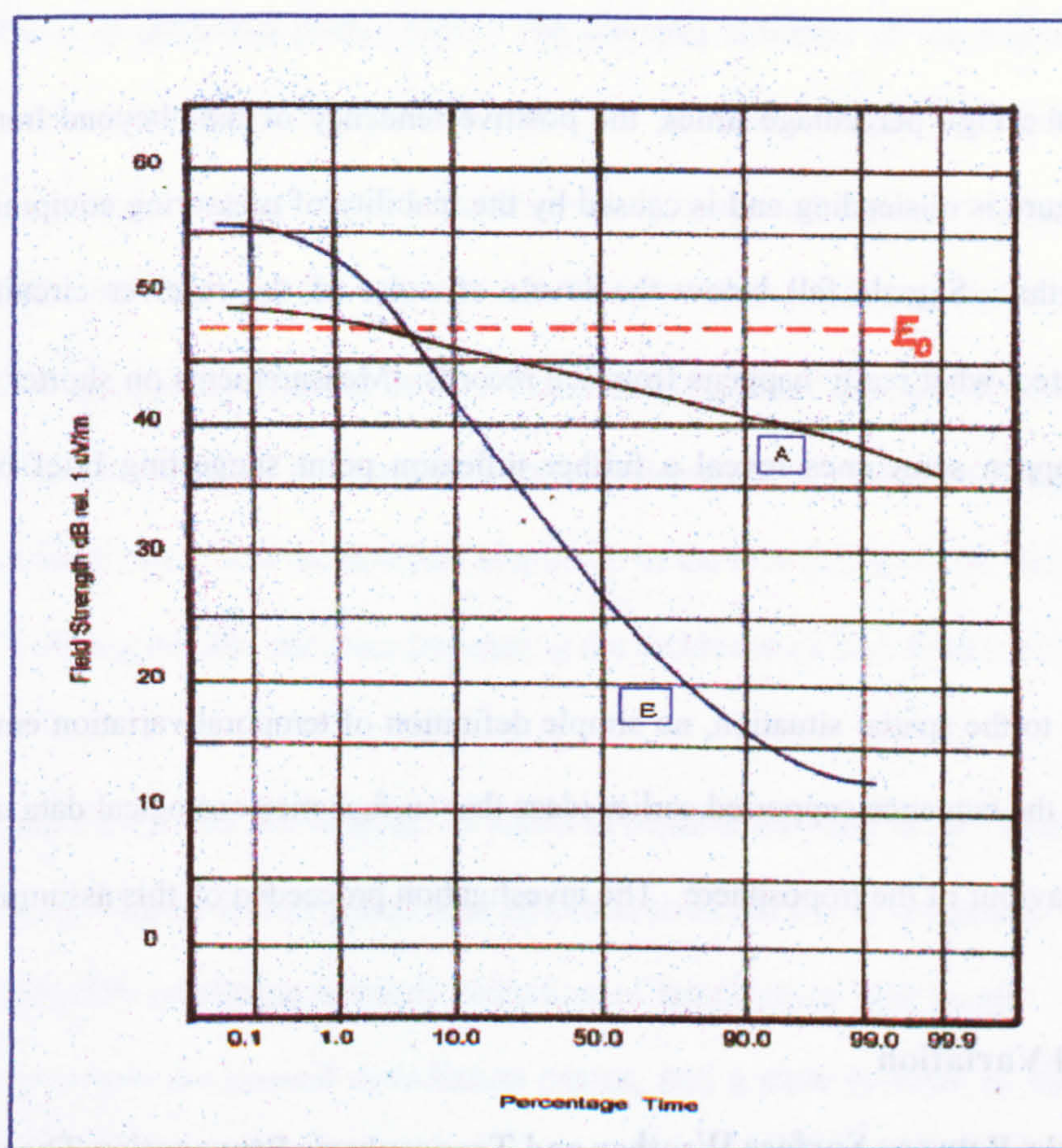


FIGURE 19
DISTRIBUTION OF FIELD STRENGTH AS A
FUNCTION OF TIME

The value E_0 is the theoretical free-space field strength at a receiving site, and curve A typifies the record of reception of a signal from a transmitter within horizon range. Curve B is an example of reception from a transmitter beyond the horizon

For trans-horizon paths the form changes to that shown in curve B, and it is important to comment upon the extremities of this. For low percentage times at the higher frequencies, field strengths during periods of abnormal propagation sometimes well exceed that of free space. Caused by additional energy reflected by or refracted through the troposphere, this contribution is particularly apparent on overseas paths where tropospheric conditions are more stable than overland. The point of interception of the curves was the original reason for the adoption in this project of a figure of 5% time as that defining the level above which propagation was regarded as abnormal. Observed from a large number of measurements the coincidence between the short-range and long-range curves often occurred at or near a distinctive point of inflexion of the latter. It was assumed that

the high field strengths then being recorded from the distant source were largely those of the tropospheric component.

With regard to the high percentage times, the positive tendency of the "beyond horizon" curve shown in the Figure is misleading and is caused by the inability of measuring equipment to detect low field strengths. Signals fall below the levels of noise in the receiver circuits, and it is impossible to detect what really happens from the records. Measurements on shorter paths where this does not happen sometimes reveal a further inflexion point suggesting brief but complete "drop-outs".

Thus in contrast to the spatial situation, no simple definition of temporal variation emerged in the early stages, but the evidence supported earlier ideas that surface meteorological data might help to interpret the behaviour of the troposphere. The investigation proceeded on this assumption.

4.3. Temporal Variation

4.3.1. The Links Between Surface Weather and Tropospheric Propagation Theory

The refractive index variations in the troposphere create a situation similar to that at lower frequencies in which energy is returned to earth from the ionosphere. What happens at the greater altitudes is of little interest here; the ionospheric layers are largely transparent to the VHF/UHF bands, most energy not refracted back towards earth in the troposphere will pass through and be lost into space. There are exceptions to this, affecting the VHF band, in which reception over long distances is made possible by reflection at upper layers, creating the phenomena of sporadic E^(4.2) and trans-equatorial propagation^(4.3). The former affects frequencies below 75 MHz, energy being returned to earth from the E layer, about 125 km above the earth, and constantly varying in density with the sun's altitude. Extremely high field strengths have been recorded, and limited the use of the lower VHF channels for television as described in Chapter 1. Trans-equatorial propagation affects higher frequencies in the VHF bands, and although its effects are less evident it is a feature widely reported in some detail by amateur radio enthusiasts.

Before describing the examination into the effects of weather upon propagation it is useful briefly to review the basic theory, because this illustrates the links between the meteorological conditions and the incidence of abnormal propagation. The physical structure of the troposphere is highly complex, and more fundamental research could be undertaken with the measurements now available. For example, at short ranges within line-of-sight of a radar source where there is concern about the interference between the various contributions to the received signal which affect its coherence, ray tracing methods could be used that take account of tropospheric discontinuities^(4.4), and it might well be possible to investigate these. However, in the point-to-area broadcasting bands the immediate concern is the absolute amplitude of the interfering signal, so interest has been confined to producing reliable statistics forecasting the incidence of high field strength levels.

The troposphere is a thin but active layer. It varies in depth from 7 km at the poles to 17 km at the equator, and is the volume within which heat absorbed from the sun is re-radiated by the earth, its neutral state normally producing a steady reduction of temperature with height. The tropopause marks the point where the general re-radiation ceases, and a slow increase in temperature starts through the stratosphere. Importantly, the troposphere contains about 80% of the total mass of air around the earth, and 90% of the atmospheric moisture. These components are often in turbulence, when changes in temperature, atmospheric and water pressure, combine to influence the neutral state. In the latter condition, there would be a slow reduction in the refractive index of air with height, as it decreases in density. This causes radio ray paths to curve slightly towards the earth, and the laws of optical refraction provide a reasonable explanation for this - hence the simplistic approach used in field strength prediction of modifying the theoretical curvature of the earth.

The vertical structure varies much more rapidly than the horizontal, typically by two orders of magnitude, and a very confused situation can confront a ray representing a propagation path. The troposphere can be considered to be horizontally stratified on the largest scale of distance (> 1000 km), whilst on the medium scale (100 - 1000 km) the topography and local meteorology can create substantial fluctuations in the strata. On the smallest scale (< 100 km), turbulent mixing of the air locally can cause scattering and scintillation of the signal, completely disrupting the concept of a

coherent layer.

The index of refraction n of air is very close to unity; the index at the earth's surface n_0 is about 1.0003, falling to unity at a great height, demonstrating its slight deviation. For this reason it is customary to use the practical N-unit ^(4.5), a dimensionless quantity approximated at radio frequencies by

$$N = (n - 1)10^6 = 77.6 \frac{P}{T} + 3.73 \left(10^5 \frac{e}{T^2} \right)$$

where P = atmospheric pressure (mb)
 T = absolute temperature ($^{\circ}\text{K}$)
 e = water vapour pressure (mb)

This may be separated into dry and wet terms, thus:-

$$D = 77.6 \frac{P}{T}$$
$$W = 3.73 \left(10^5 \frac{e}{T^2} \right)$$

In a state of equilibrium, with no heat sources, the decrease in pressure P with height is balanced by gravity. Because of the gravitational stratification, the temperature varies with height even under adiabatic conditions, and the lapse rate of dry air is about 1°K per 100m. If the air is saturated, the lapse rate is lower (about 0.6°K per 100m.), because condensation releases latent heat which counteracts the adiabatic cooling due to pressure change. Water vapour pressure also decreases with height under the influence of gravity, but this decay is offset by a decrease in the saturated vapour pressure with temperature, which varies from about 23 mb at 20°C to 6 mb at 0°C . As height increases and temperature decreases, the air above is saturated and precipitation occurs. Thus water vapour pressure decreases more rapidly with height than pressure, and is negligible above 3 km.

The result of the variations in pressure, temperature and water vapour pressure is that under neutral conditions N decreases with height, its average behaviour following the exponential decay:-

$$N = N_s \exp[-z/Z]$$

where N_s is the surface value of N
 z is height above the earth's surface
 Z is a scale height

The CCIR reference atmosphere has the value $N_s = 315$ and $Z = 7.35$ km. Worldwide maps of N_s are published ^(4,6) which show the variations in radio refractive index. This is related to sea temperatures, the highest values of N_s being achieved in equatorial regions, and land-locked areas of water in temperate zones, e.g., the Mediterranean and Black Seas. Similarly, ocean currents bringing relatively warm water into temperate zones produce increases in N_s , thus the values are marginally higher in the western approaches to the British Isles than they are in the North Sea.

The different rates of decay with height of the wet and dry terms of the basic formula for N lead to the bi-exponential model:-

$$N = D_s \exp[-z/Z_d] + W_s \exp[-z/Z_w]$$

Maps of Z_d , Z_w , D_s and W_s are published showing worldwide conditions ^(4,6), and values of $Z_d = 9$ km and $Z_w = 2.5$ km are typical. The dry term D_s makes a relatively constant contribution to N and the wet term W_s provides most of the variability of N.

The decrease of N with height, bends rays towards the earth's surface but is insufficient under normal circumstances to overcome the curvature. Analysis of measurements led to the early suggestion that calculations of ray propagation could be carried out assuming the curvature to be increased by the factor of 4/3. An alternative approach to the calculations, not pursued here, is to replace the earth with a flat plane and adjust the path of the ray so that the relative curvature is maintained. This is a process much used in mathematical analyses of the atmosphere.

The constant mobility of the troposphere, especially at low levels where the influence of the earth's surface weather is greatest, causes substantial variations about the average decrease of 40 N

units/km. Cross sections of the troposphere can be obtained using tephigrams - temperature-entropy charts obtained during aerosonde ascents - but these are of limited value to those analyzing radio propagation conditions because of their lack of detail ^(2.16, 4.7). However, the stability of air masses is a vital guide to the extent of refractivity. If the rate of decrease of temperature with height is less than that of the dry or saturated lapse rate, e.g., cooling from below or heating from above, then the mass is described as "stable". This situation occurs when warm air passes over the top of cold. If the temperature increases with altitude instead of decreasing, an inversion exists, and there is total stability. If the rate of temperature loss is greater than the dry or saturated lapse rate - cooling from above or heating from below, then the mass is "instable".

Observations of cloud cover in weather reports can reveal the extent of stability, because convection clouds, typically cumulus, cease to grow when air in rising thermals become colder than the environment. This is an indication of a stable atmosphere. Conversely, in the instable state there is considerable vertical turbulence, condensation continues and cumulus develops into cumulo nimbus towering several kilometres. The part of an anticyclone where temperature inversions are likely to be created is where stable or a slowly changing balance has been struck between dry, warm subsiding air and moist, cool turbulent air, extending upwards from the ground. This leads to the rapid decrease of the refractive index within a short range of height. An inversion will not be formed when the descending air meets with too little turbulence - a situation in which the vapour pressure decreases and the surface temperature rises - or where there is too much.

Apart from local fluctuations caused, for example, by advection currents along the coast where warm air flows from the land over a cool sea, conditions above large sea areas change relatively slowly. Overland, there is usually a greater range of temperature caused by the sun's cycle, at least during the day. The undulations of the terrain break up tendencies to stratification, although flat areas adjacent to the coast may extend the oversea characteristics inland.

Over a given height range, refractivity profiles can be categorized by the change in N as subrefractive, normal, superrefractive, or ducting ^(4.8). Under subrefractive conditions, in which the

ratio dN/dz is greater than -40 N units, diffraction towards the earth is less than normal. Superrefraction defines an increase above normal, i.e., the ratio is less than -40 N units. Random fluctuations give rise to troposcatter, but in extreme cases of superrefraction, at levels below -157 N units, ducts can be created, within which signals are trapped and sometimes transmitted over great distances, depending upon the horizontal extent and height of the refracting layer. Both will obviously affect the size and location of the ground area which will receive signals via this route, and two main types of ducting can be identified in terms of their altitude - surface and elevated.

Surface ducts are often created by evaporation from large surfaces of water, they are very common, and their thickness is influenced by heat, being greatest at low latitudes in summer, and during daylight hours ^(4.9). The air in contact with the sea is saturated with water vapour, which by turbulence passes to higher levels. Here, however, the air is not usually saturated, and there is an above-normal decrease in the water vapour pressure over the first few metres. The thickness of this form of surface duct is related to latitude, and for example varies from about 15 m. in the Mediterranean to 5 m. in the North Sea. The depth and shape of surface ducts can be estimated using existing models ^(4.10) by measuring temperature, water vapour pressure, and wind speed a few metres above the surface of the sea, but very precise observations are needed to achieve accurate results.

Another form of surface duct is that created by advection in coastal regions. Within an air layer, humidity decreases as the warm air flows off the land, temperature increases, and a duct is formed. Advection ducts are believed to occur for 10% to 20% of the time in the southern North Sea, but much more frequently in hot climates. In low lying coastal areas, such as the east coast of England, the effects extend inland.

Elevated ducts include those created by subsidence, for example the outflow of air near the surface in a high pressure system creates a slow settling of dry air towards the centre of the system. The situation, which often extends over hundreds of square kilometres, is characterized by an increase in temperature accompanied by a decrease in humidity as the dry air descends. The radio

meteorological features of ducts associated with high pressure centres have been described ^(4.11). In the European area, subsidence inversions associated with high pressure areas are relatively rare, but they can extend for hundreds of kilometres and create conditions suitable for abnormal propagation over long distances.

Brief but relatively extensive inversions can be formed by the passage of weather fronts, superrefractive conditions being created by the warm variety (warm air moving over cold), and subrefractive by the movement of cold air. These features give rise not only to substantial changes in the levels of field strength, but also produce characteristic differences in the fading of the signal. Distinct from subsidence, the cooling of the earth's surface after sunset can also create radiation inversions, but whether or not these lead to superrefractive conditions depends upon the humidity profile, especially in temperate zones. Certainly nocturnal radiation inversions on overland paths, combined with subsidence at higher levels, can produce an abnormal propagation environment. This type of inversion is more common in summer than winter because strong winds and cloud cover are less likely, the ground is drier and more easily cooled, so the likelihood of stronger humidity gradients is increased.

In addition to the relatively large weather-related changes in the troposphere, small irregularities in the medium are a permanent feature. Their behaviour is less easy to forecast, but they create additional scattering and scintillation. As will be seen, their effects upon field strength statistics were sometimes ignored in LDR recordings.

A limited examination of the use of meteorological records to assist with the interpretation of LDR measurements was part of an earlier project ^(4.12). This achieved some success, and positive correlation between surface pressure and abnormal propagation measured along a number of paths was demonstrated. However, the conclusions were based upon only 15 LDR experiments, and other information in the daily meteorological reports which suggested avenues for further research were not pursued. In this project, the investigation has been very substantially widened.

4.3.2. The Extended Data Base Used for the Meteorological Study

Data were collected from 88 comprehensive LDR experiments completed between 1954 and 1976. These totalled about 130 years of measurements, involved 46 propagation paths, and are listed at the end of this chapter as Annex 1. Of these experiments, 83 lasted for more than 12 months, and a review of these endorsed the use of an annual base for subsequent analysis. In the majority of cases a period of one year revealed the full range of weather conditions affecting the temporal distribution of field strength, although an attempt at further subdivision using the conventional distinction of spring, summer, autumn and winter was abandoned because patterns were too irregular. In addition to these experiments, results from short-term measurements providing additional information concerning the influence of local topography, transitional effects at the coast, receiving antenna height gain, polarization differences, etc. were also included.

Wherever possible the original chart recordings of the 88 experiments were re-examined, together with the reception analyses. The latter recorded the number of minutes attained by each level of field strength through two periods of the day, from 08.00 to 18.00, and from 18.00 to closedown, usually around 23.00. Experiments during which measurements continued during the whole 24-hour period were also included.

Meteorological data were taken from the six-hourly weather reports issued by the network of shore stations, the locations of which appear in Figure 20. Reports were also obtained from one weather ship, and from various off-shore oil and gas rigs, so a reasonably detailed picture of the ongoing weather situation in the UK and its surrounding seas was produced. The items recorded included surface pressure, wind direction and speed, air temperature, dew point temperature, and cloud form and height. Wind direction was sub-divided to show the eight cardinal bearings, i.e., at horizontal intervals of 45° , but as described below this was eventually modified. Cloud form definition was also abbreviated, because the original reports identified no fewer than 30 types. To investigate various anomalies additional data in the daily reports were also extracted, such as visibility and rates of barographic change. For example, the incidence of fog could indicate superrefractive

conditions with air temperatures higher than those of the sea. Unfortunately the processing work was very labour-intensive and time-consuming. The information was only available in hard copy that could not be removed from the Meteorological Office, and for this reason the full six-hourly data were obtained initially for only four of the 19 years covered by the principal experiments listed in Annex 1 (1955, 1957, 1961 and 1963). The detailed examination concentrated on results for those years, although further data were processed later to cover additional periods.

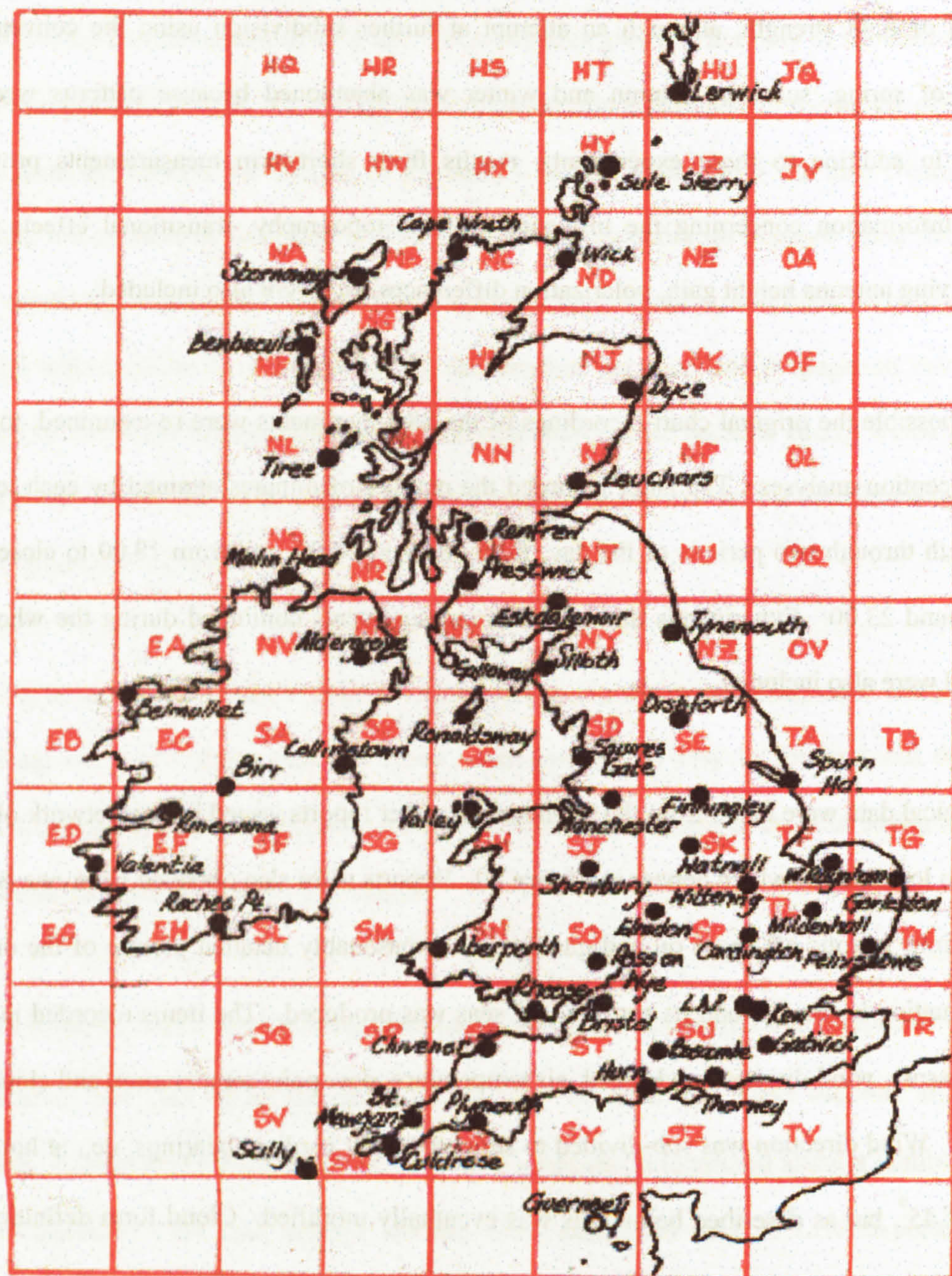


FIGURE 20
LOCATION OF SHORE STATIONS IN METEOROLOGICAL OFFICE NETWORK

The results of the examination confirmed that the selected weather parameters were reliable indicators of propagation conditions in the troposphere. However, the relationships between the detailed weather data along each path and the field strength measurements were complicated, and presaged a complex prediction. Fortunately, the examination also exposed the unique importance of the wind source in determining the tropospheric stability, and in the search for a simpler approach the field strength measurements were compared with data describing the airstreams across the UK. A brief review of the nature of weather patterns may be useful.

Within the earth's atmosphere large, semi-permanent anticyclones exist within the polar and sub-tropical regions. Sporadically there is an outflow of air from these regions into the temperate zones, and the constitution of these pockets is then materially affected by the surfaces over which they pass, for example, their moisture content may be substantially increased by passing over sea areas. Differences in atmospheric pressure create anticyclonic and cyclonic centres, with fronts between them. Geographically, the British Isles is in a particularly turbulent situation, between large land and sea masses and poised between air from polar and sub-tropical regions. The situation is aggravated by the regional hydrology - the confluence of warm and cold sea currents. As a notable example, the major influence upon the climate of N. W. Europe, the Gulf Stream, is determined by constantly varying conditions along its 8000 km passage from the American east coast, around the western and northern coasts of the British Isles and on to Scandinavia. Broadly, the influence of the airstreams upon the stability of the upper air can be summarized by considering the five main air masses which approach the UK.

a) Polar Continental: Cold and dry, this airstream originates in Scandinavia or Russia, and approaches the UK from an easterly or north-easterly direction across the North Sea. It generally affects this country in the winter, and its moisture content depends upon the length of the oversea section. A short passage over the North Sea, with an anticyclone over Scandinavia, can produce stable air conditions and advection ducting, but this situation is only likely in summer when the sea is cool, the land is relatively warm and there is little wind.

b) **Polar Maritime:** Cold and fairly moist, this airstream comes from the Canadian Arctic or from Greenland, and generally reaches the UK around a depression passing to the north of this country. A sub-division is identified as "Arctic Maritime", originating from an anticyclone to the west or north west of the UK. The cold air may be warmed by the sea, although the extent of heating depends upon the mixing of the Gulf Stream and currents coming down from the Polar regions through the Denmark Strait around Iceland. As the centre moves eastwards across the top of the UK, the air becomes drier and much colder. From a limited arc it approximates to the polar continental stream, but is truly arctic, colder and much drier. It is an airstream which is unlikely to increase tropospheric stability.

c) **Returning Polar Maritime:** Again cold air coming from the Arctic, but this time passing anticlockwise around a large depression to the north west or to the west of the UK. The cold air moves initially southwards down the Atlantic, and collects more moisture and increasing warmth on the long oversea path. Eventually the anti-clockwise spin of the depression brings it to the UK from the south west, or even from the south, causing some cooling of the lower layers as the air now moves northwards, with further addition of moisture. This situation tends to increase the stability of the troposphere.

d) **Tropical Maritime:** Warm, moist air coming from the Azores or even from the Caribbean. It is cooled by the sea and becomes more stable but its moisture content is high. Approaching the UK from the south west, usually from the north side of an anticyclone, its effects can be felt across the southern areas of the UK. These highs often extend their area by building northward.

e) **Tropical Continental:** These airstreams reach the UK from the south or south east, and originate in North Africa, or occasionally in the summer from Central or even Eastern Europe. They are hot and dry, only those passing over the Mediterranean and/or the Bay of Biscay having significant moisture content. Again the tendency is to increase the stability of the troposphere.

The transitory influence of fronts has already been mentioned. Usually boundaries between polar

and tropical maritime air, their effects will depend upon the change of temperature they introduce, thus a warm front over a cold layer may produce superrefractive conditions.

Very useful information describing the general airstream pattern within the area 50° to 60° N and 10° W to 2° E was found in a Meteorological Office publication ^(4.13). It identified a single predominant airstream each day, its author having analysed 150,000 synoptic charts covering the period 1861 - 1971, and recorded the origin of each wind based upon seven basic types - anticyclonic, cyclonic, westerly, north-westerly, northerly, easterly, and southerly. It employed a total of 27 basic and hybrid conditions for specialist meteorological purposes, although the author of this thesis revised the categorization to concentrate on the likelihood that a particular wind would increase or decrease the stability of the lower troposphere. The propagation examination covered the period offering the largest quantity of field strength measurement records, i.e., 1940 - 1971, and the daily airstreams across the UK during these years were categorized as shown in Table 20.

The prefix A in the first column shows the airstream was created by the clockwise flow around a high pressure centre, thus AN describes the arctic maritime wind coming from an anticyclone centred to the west of the British Isles, a generally cold air over cold sea condition unlikely to affect the stability of the upper air. The prefix C denotes the opposite current from a depression, so CS and CSW are airstreams arising from depressions to the west and north-west which, although passing through cold air in the north, will be influenced by the nature of their subsequent passage south, east and then north across the Western Approaches. As a result the upper air may be stabilised by the processes previously described. The final column in the table shows the duration of each airstream as a percentage of the average year, using as a base the period of 32 years, and from this it can be deduced that conditions which *may* enhance propagation conditions are likely to occur for more than 50% of the time. The single pressure value shown in the penultimate column is the mean of the five daily figures obtained from the weather station at Manchester, and four peripheral stations at Hurn (south), Spurn Head (east), Lerwick (north), and Valentia (west). However, in the case of oversea propagation paths approaching the UK from the south and east,

which include the great majority of those from which interfering signals now originate from the continental mainland, the inclusion of the Lerwick reading usually reduced the average pressure result, a feature regarded in this analysis as a distortion. Thus the table shows in parentheses what is believed to be a more representative pressure value for these airstreams, which excludes the Lerwick result.

AIR STREAM	MET. OFFICE CATEGORY	WEATHER CENTRE RELATIVE TO UK	AIRSTREAM STABILITY	AVERAGE PRESSURE (mb)	% TIME
AN	Arctic Maritime	High to West		1012	4.8
CN	do.	Low to East		1002	4.1
ANE	do.	High to North-west		1014	1.8
CNE	Polar Continental	Low to South-east		999	0.8
AE	do.	High to North	Summer inc.	1019 (1024)	4.6
CE	Temperate Continental	Low to South	do.	1006 (1008)	3.3
ASE	do.	High to North-east	do.	1018 (1024)	2.2
CSE	do.	Low to South-west	do.	1004 (1005)	1.4
AS	Tropical Continental	High to East	Increase	1027 (1032)	3.5
CS	Returning Polar Maritime	Low to West	Increase	1009 (1012)	3.1
ASW	Tropical Continental	High to South-east	Increase	1025 (1030)	3.1
CSW	Returning Polar Maritime	Low to North-west	Increase	1009 (1011)	7.3
AW	Tropical Continental	High to South	Increase	1026 (1033)	10.8
CW	Polar Maritime	Low to North		1006 (1006)	9.7
ANW	Tropical Maritime	High to South-west	Increase	1019 (1028)	3.6
CNW	Arctic Maritime	Low to North-east		1004	2.9
A	Anticyclonic (High)	Note 1	Increase	1024	18.9
C	Cyclonic (Low)	Note 2		1005	14.1

TABLE 20
AIRSTREAMS IN THE PERIOD 1940 - 1971 AFFECTING THE UK

The table identifies the airstream approaching the UK, and the position of its source weather centre. Its tendency to increase the stability of the upper air contained within it is shown, together with the average surface pressures, and the percentage incidence during the period.

Note 1. High pressure centred over UK

Note 2. Low pressure centred over UK

One other observation must be made concerning atmospheric pressure. The reports showed the annual variation of this parameter recorded four times daily at each meteorological station produced a generally normal distribution about the local median. The surface pressure decreases with latitude as the depth of the troposphere reduces, thus the median in the Channel Islands is about 1017 mb and that in Shetland is 1008 mb. Figure 21 illustrates one example, showing the situation at the latitude of the southern part of the North Sea recorded at the time of the tests. This approximates a normal distribution and has a mean at 1016 mb, appropriate to the latitude. Over

the period the annual medians displayed very little change, although some skew in the distribution was obvious. This provided an indicator to the incidence of abnormal propagation for each year, a feature already mentioned in connection with Figure 18.

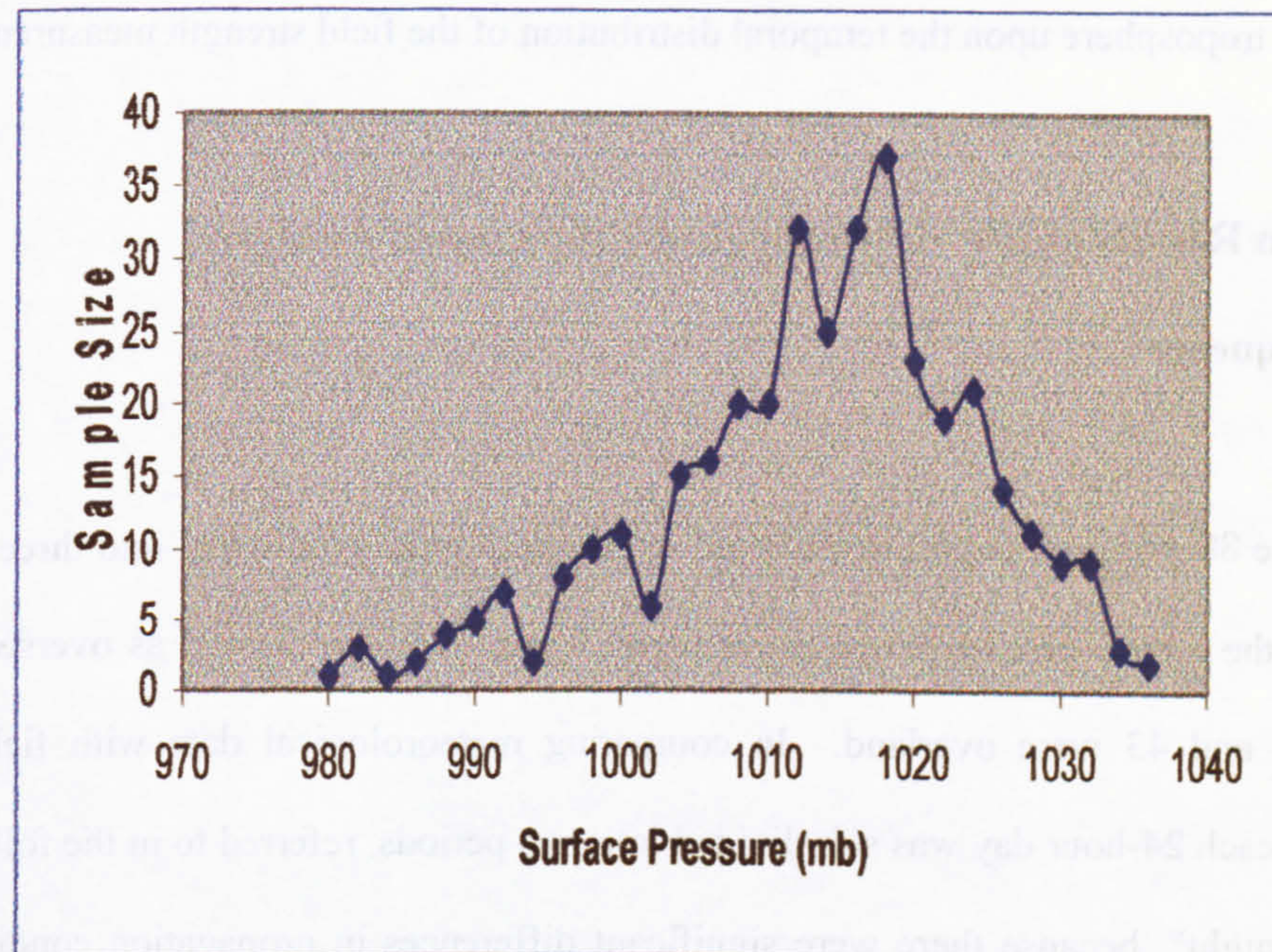


FIGURE 21
ANNUAL DISTRIBUTION OF DAILY SURFACE PRESSURES
RECORDED IN EAST ANGLIA AND ADJACENT SEA AREAS

Thus three types of data were prepared for the study. Firstly, the field strength measurements, secondly the weather reports, and thirdly the daily airstream tables. The value of the first cannot be overstated. At the time the measurements were made, the radio spectrum was relatively empty, and few transmitters were in operation. There was no confusion concerning the transmission source, or the propagation path under investigation – now completely unrepeatable circumstances. Within the European area only a few hundreds of kilowatts were being radiated on the VHF and UHF channels, compared with the many hundreds of megawatts now. (Incidentally, this last point raises a possibly rhetorical question to which reference is made later – to what extent has this vast increase in electromagnetic radiation modified the troposphere, has it contributed to the infamous “global warming” and subtly affected the transmission medium?) Of course, the limited surface meteorological data gave only a few clues concerning the behaviour of the troposphere, and other evidence was reviewed, notably radiometeorological experiments described by many researchers,

of whom one is referenced here^(4.14). Records of the solar constant and the sun-spot cycle were also compared with the field strength measurements, but none of these separate exercises produced encouraging results, although they had to be restricted to meet a realistic time scale. However, it is believed the results of the study described below provided a pragmatic interpretation of the influence of the troposphere upon the temporal distribution of the field strength measurements.

4.4. The Main Results of the Meteorological/Propagation Analysis

4.4.1. The Sequence

At the outset the 88 principal experiments listed in Annex 1 were subdivided into three categories determined by the nature of each propagation path. Thus, 33 were classed as oversea, 12 were mixed land/sea and 43 were overland. In comparing meteorological data with field strength measurements, each 24-hour day was sub-divided into two periods, referred to in the following text as "day" and "night", because there were significant differences in propagation conditions. For measurements made between 06.00 and 18.00 (day), the weather data reported at 06.00, 12.00 and 18.00 were used. Between 18.00 and 06.00 (night), the information was taken from the 24.00 report. Where additional details were needed to investigate periods of nocturnal abnormal propagation, meteorological data were interpolated for 21.00 and 03.00. The investigation passed through the following phases:-

- i) The relationships between surface pressure and abnormal propagation were examined, using the results recorded during every day and night period along each propagation path.
- ii) A fuller picture of the dynamic situation during periods of abnormal propagation was obtained using additional information from the detailed weather reports appropriate to each propagation path.
- iii) With evidence from i) and ii), the technique of using only the single daily airstream result to predict periods of abnormal propagation was investigated.

The following description deals firstly with results from the years selected from the experiments for detailed study, and then reports the outcome of the use of the single airstream analysis.

4.4.2. The Detailed Study

The results from the examination of oversea paths are reported first, because these provide the clearest illustration of the important factors. The series of 25 experiments across the North Sea listed in Annex 1 were particularly useful, because they were conducted over the same paths for a series of frequencies throughout the VHF/UHF bands. The number of periods recorded during the four selected years is shown in Table 21 together with the total hours for which recorded data were extracted for analysis. These reveal that only a fraction of the results was used; in such a complex experiment occasional equipment faults and other operational difficulties were inevitable, and suspect information was omitted. Just over 42,000 hours of day recording (48% of the total), and about 23,000 hours of the night periods (26%) were accepted.

RECEIVING SITE (TX. AT SCHEVENINGEN)	YEAR	FREQUENCY (MHZ)	NUMBER OF PERIODS		DURATION (HRS)	
			DAY	NIGHT	DAY	NIGHT
Happisburgh	1955	94.35	191	187	1622	903
Flamborough Head	1955	94.35	193	190	1668	921
New ton	1955	94.35	188	192	1647	934
Aberdeen	1955	94.35	201	199	1731	947
Lerw ick	1955	94.35	193	180	1680	842
Happisburgh	1957	187	230	221	2004	1078
Flamborough Head	1957	187	232	235	2047	1133
New ton	1957	187	227	216	2029	1061
Aberdeen	1957	187	213	217	1826	1073
Lerw ick	1957	187	224	222	1928	1098
Happisburgh	1961	560	165	171	1460	842
Flamborough Head	1961	560	170	168	1518	831
New ton	1961	560	174	176	1515	853
Aberdeen	1961	560	178	177	1584	861
Lerw ick	1961	560	165	162	1469	799
Happisburgh	1963	774	352	356	3298	1758
Flamborough Head	1963	774	358	351	3329	1727
New ton	1963	774	355	329	3336	1619
Aberdeen	1963	774	337	336	3158	1642
Lerw ick	1963	774	341	340	3200	1671
TOTALS			4687	4625	42049	22591

TABLE 21
NORTH SEA LDR EXPERIMENTS DURING
THE YEARS 1955, 1957, 1961 AND 1963

Figure 22 is a typical example of the simple comparison between surface pressure and field strength. Maximum daytime field strengths measured during one year at Happisburgh of the 560

MHz transmissions from Scheveningen appear as a function of the maximum surface pressures recorded for the same periods. Although there is a definite tendency for field strength to increase with surface pressure, the overall result is incoherent and poor correlation was obtained - important contributing factors were obviously being ignored. Also, because the noise levels of receiving equipment prevented accurate measurement, results below about 20 dB μ V/m are distorted.

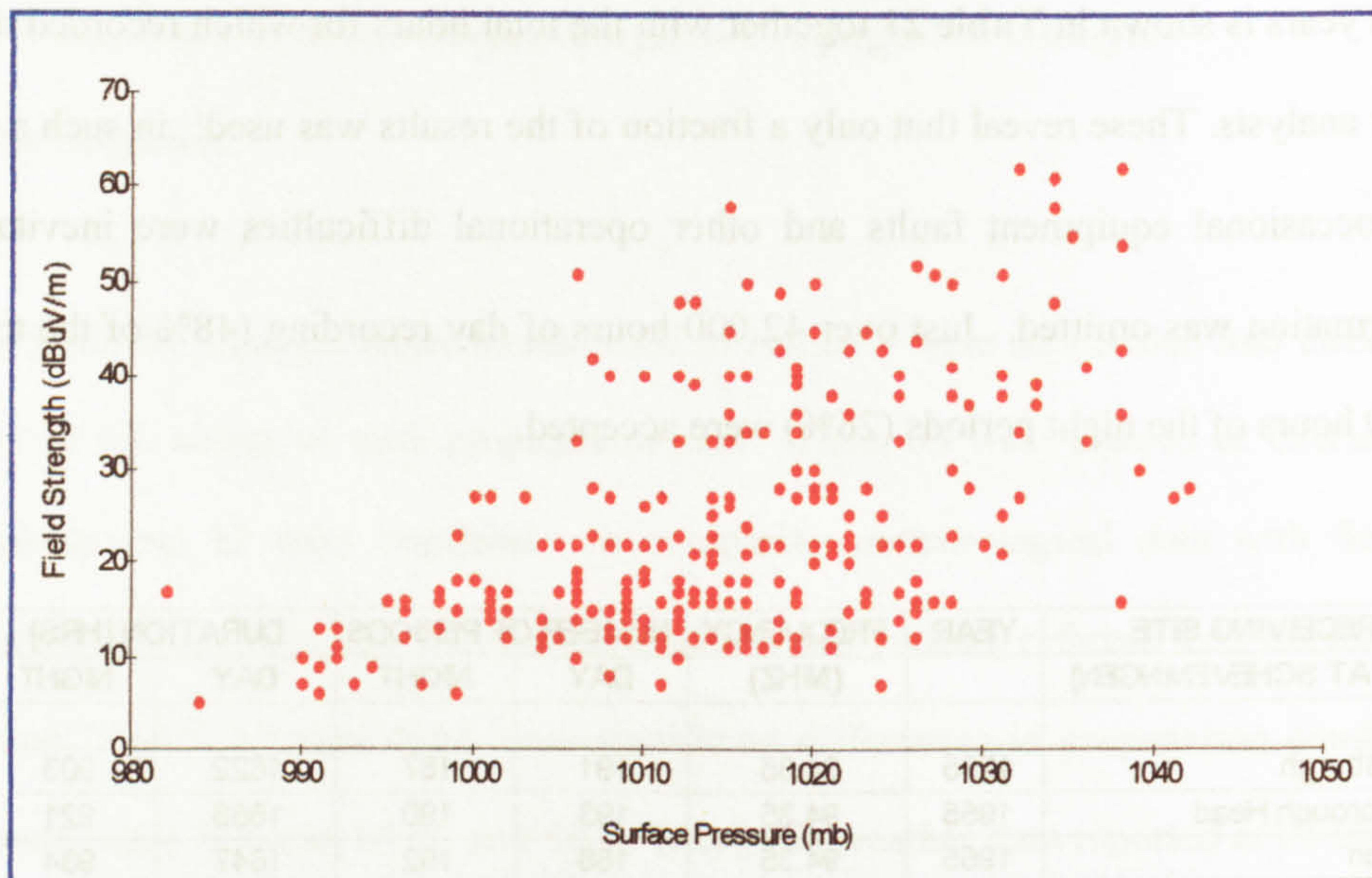


FIGURE 22
MAXIMUM DAYTIME FIELD STRENGTHS
RELATIVE TO SURFACE PRESSURES

Measurements made on 560 MHz on overseas path from
Scheveningen to Happisburgh: ERP = 1 kW

However, although the initial surface pressure comparison was disappointing, the preliminary work revealed other results. For example, the measurements from the North Sea experiments confirmed observations made at the time of the experiments ^(4.15), notably that the levels of field strength during periods of abnormal propagation increased with frequency. This is shown in Table 22 in which the 1% and 5% time results taken from LDR experiments made in the four bands of the VHF/UHF spectrum have been compared. The influence of frequency is further convincingly demonstrated by reporting the absolute maximum field strength recorded on each band against the free-space value at Happisburgh. The measurement charts were run at a speed of 10 cm/hr., and it was customary to record the average value of the trace over 1 cm. i.e., six-minute intervals. The

absolute maximum is the highest average value achieved on the recorder chart, and on Band II (94.35 MHz) it was 45 dB μ V/m, on Band III (187 MHz), 65 dB μ V/m, on Band IV (560 MHz), 76 dB μ V/m, and the Band V (774 MHz) result was 81 dB μ V/m, all quoted for an ERP. of 1 kW. During the six-minute period the trace might briefly exceed this value substantially, although this was rare at the highest levels.

RECEIVER	E _o (dBu)	BAND II (dBu)		BAND III (dBu)		BAND IV (dBu)		BAND V (dBu)	
		1% T	5% T	1%T	5%T	1%T	5%T	1%T	5%T
Happisburgh	61	30	24.5	43	34	63	48	68	47
Flamborough Head	56	23	13.5	27.5	13	58.5	31	51	22
New ton	52	9	n.l.	10	-11	44	10	32	n.l.
Aberdeen	50	-4	n.l.	1	n.l.	26	n.l.	14	n.l.
Lerwick	47	n.l.	n.l.	-11	n.l.	21	n.l.	3	n.l.

TABLE 22
FIELD STRENGTH RESULTS FOR STATED PERCENTAGES OF TIME

Transmitter at Scheveningen, ERP = 1 kW

In the next phase of the study, all available items of the surface weather information were used and provided fuller explanation of the behaviour of the troposphere. In particular, it revealed that data describing the air streams decisively supplemented the surface pressure information. This is illustrated by considering a typical example. Figures 23 (surface pressures) and 24 (field strength) show results from the North Sea experiments on 560 MHz for the two shortest paths during February/March 1961. Each curve shows the maxima for a series of twelve hour periods. Although the pressure and field strength curves are broadly similar, explanation for detailed deviations is provided by reporting the sequence of events revealed by the meteorological data.

At the beginning of the period, a depression to the north of the UK, the source of a dry, polar maritime airstream, was moving away into Scandinavia. During the 28th February, with the pressure along the two paths averaging 1019 mb, the wind backed towards the south, as a ridge of high pressure bringing tropical maritime air approached from that direction. The influence of this was first obvious on the more southerly Happisburgh path with a steady increase in field strength beginning during the 2nd March, but there was no reception at Flamborough Head. The initial

increase in pressure there, at about 1020 mb, was accompanied by variable winds and dense fog.

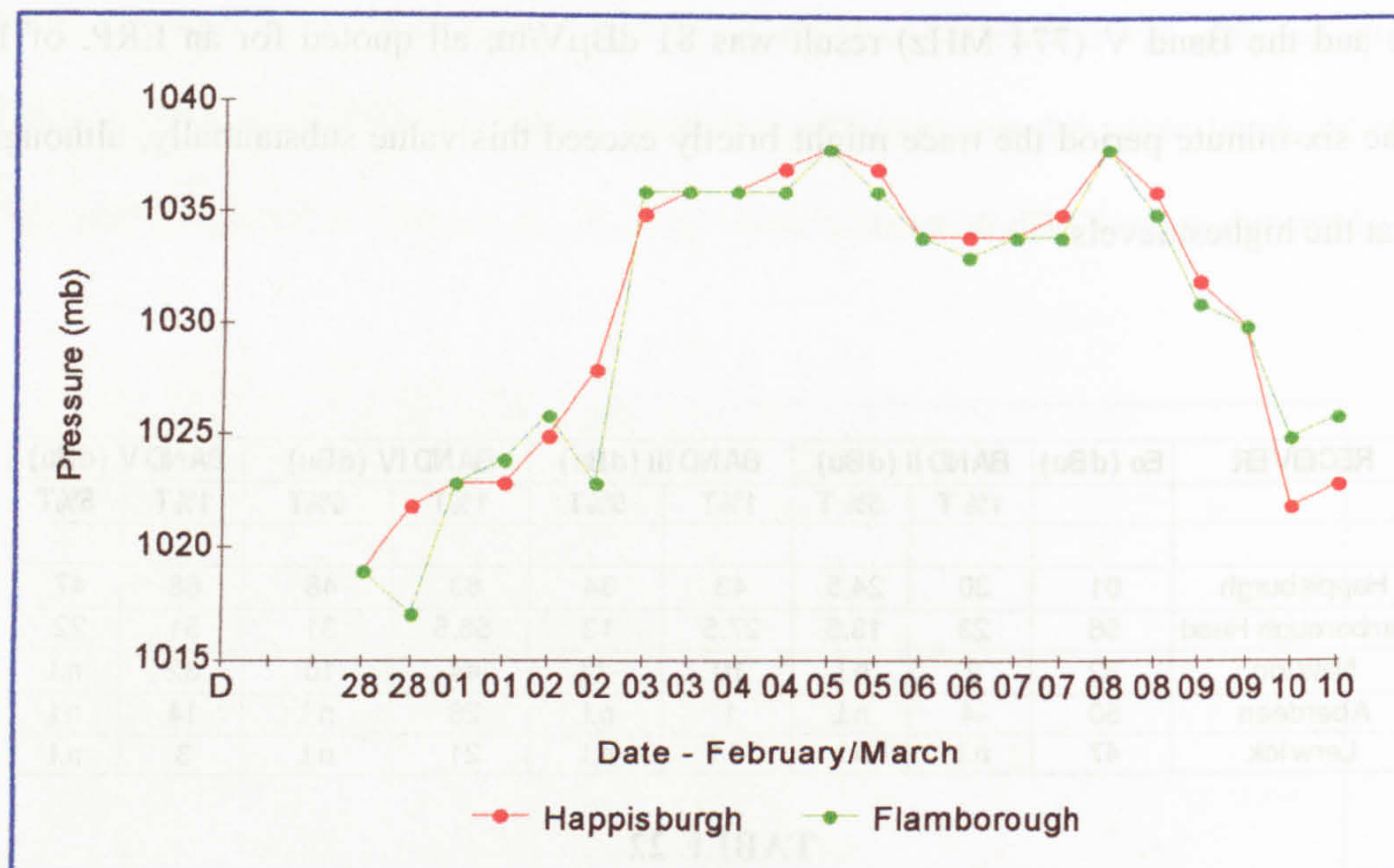


FIGURE 23
SURFACE PRESSURES IN THE SOUTHERN NORTH SEA

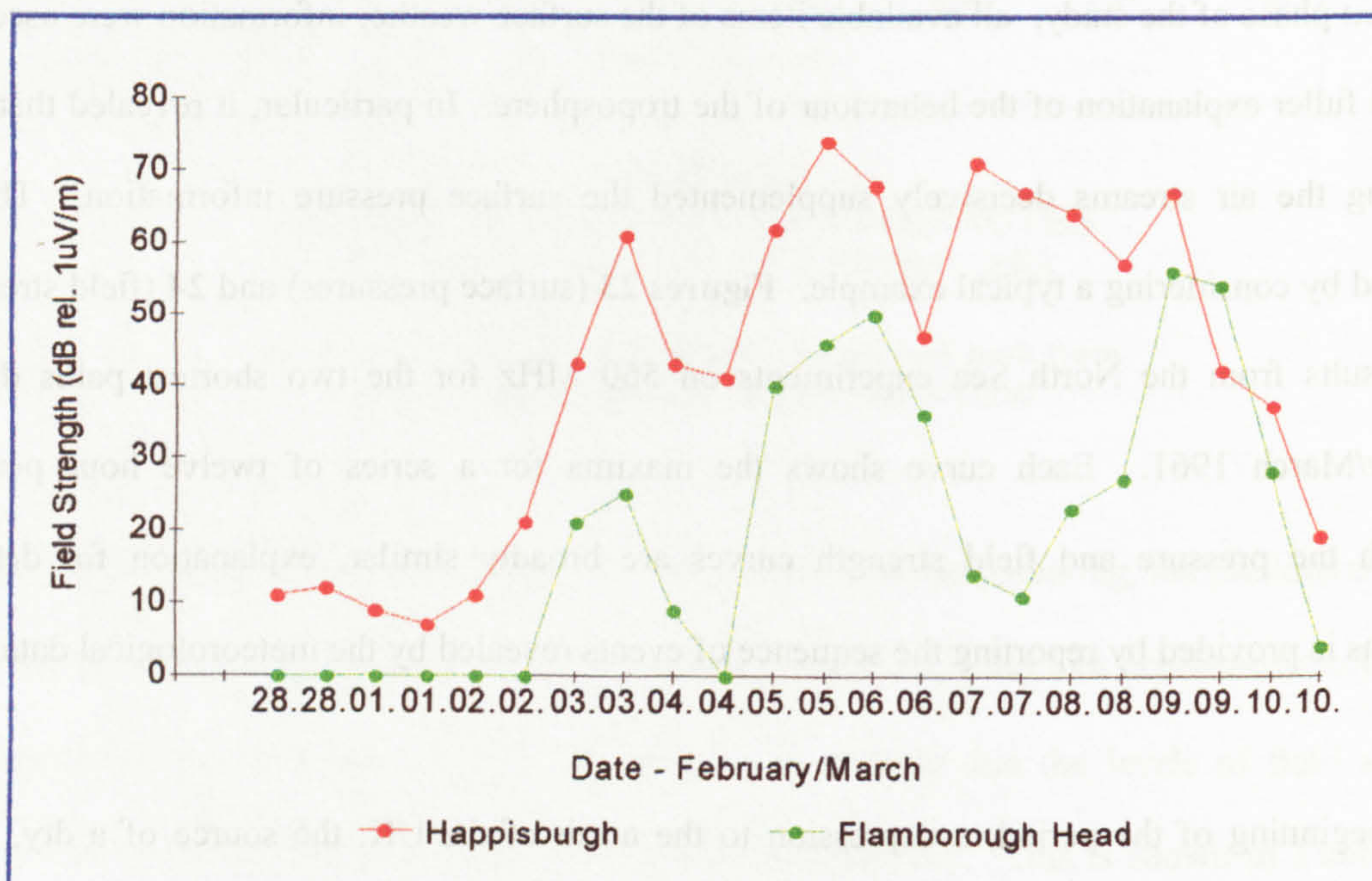


FIGURE 24
FIELD STRENGTH MEASUREMENTS
SCHEVENINGEN - HAPPISBURGH AND FLAMBOROUGH HEAD

Pressure continued to build as the wind veered, and on the morning of the 3rd March there was a significant increase in field strength at both receivers as relatively warm air came in over the cold sea. Pressure rose rapidly to 1036 mb and the field strengths increased, reaching free space level

on the shorter path. Graphs of the distribution of field strength during each twelve-hour period showed the characteristic shape in which abnormal propagation is revealed by an increasingly obvious point of inflexion. Favourable upper air conditions existed along both paths and high field strengths persisted for long periods.

However, although there was no reduction in surface pressure, a very rapid decrease in both signals occurred during the morning of the 4th March, as the main wind stream came directly through the English Channel into the southern North Sea. Travelling over a long stretch of water, the air was saturated, a dense radiation fog formed in the light winds and spread across the Dutch coast, creating an inversion very close to the surface of the sea at the transmission end. This attenuated the previous abnormal propagation mode via an elevated layer. The fog cleared during the early morning of the 5th March as the anticyclone built over France and the wind backed towards the south. Pressure increased to a maximum of 1038 mb on both paths that day, but the field strengths did not reach their highest levels until the evening, when the anticyclone receded to the south.

The next day a steady decline in field strength began, although with pressure maintained above 1030 mb abnormal reception conditions continued until 9th March, when the ridge collapsed and pressure fell below this level. The brief return to abnormal conditions with pressures still in the vicinity of 1030 mb which occurred during the 9th March is noteworthy, however, because for a short spell during the night the signal received over the longer path exceeded reception levels at Happingburgh by a substantial margin. This is attributed to a combination of subsidence and radiation inversions at the coast near Flamborough Head. Wide fluctuations in surface readings were recorded at the nearby Spurn Head meteorological station, and the excess pressure persisted for a further day, although received field strengths rapidly dropped back to their normal levels.

Many similar examples underlined the close relationship between the nature of the airstream and the incidence of abnormal propagation. Periods of the latter within each twelve-hour period were correlated against the wind source, initially subdivided into the eight cardinal directions, described earlier. This proved positive for frequencies above 100 MHz, although measurements made at

94.35 MHz could not be assessed, due to the almost complete absence of the distinctive inflexion point defining this feature. As shown in Table 23, of 7,398 twelve-hour periods of measurements above 100 MHz available for analysis, 931 (15%) contained an incident of abnormal propagation. About 77% of the abnormal propagation incidents occurred during the periods when winds were from the S.W. quadrant (S., S.W., and W.).

RECEIVING SITE	SAMPLE	A.P.	SOURCE OF AIRSTREAM							
	SIZE	INCIDENTS	N	NE	E	S.E	S.	S.W.	W.	N.W.
Happisburgh	1495	428	2	11	21	42	86	104	136	26
Flamborough Head	1514	306	1	4	7	19	72	82	103	18
Newton-by-the-Sea	1477	129	0	2	2	5	25	34	45	16
Aberdeen	1458	47	0	1	0	2	7	19	12	6
Lerwick	1454	21	0	1	0	2	4	10	3	1

TABLE 23
NORTH SEA EXPERIMENTS

Source of airstream during periods of abnormal propagation

The examination of the conditions in the North Sea was extended to include English Channel experiments, and those from other oversea paths to the UK mainland. The Channel results were particularly interesting because all the paths were shorter than those across the North Sea, and provided data concerning the transition over a smooth surface from line-of-sight to beyond-horizon conditions. Because the paths were shorter, the signals were well above the noise levels of the receiving equipment, and new information was obtained about the total range of variation with time. The experiments included reports on the effects of polarization of the transmission and the value of space diversity, involving simultaneous measurement of reception through receiving antennas separated by small distances. Some other previously unpublished results for this area included measurements using receivers installed on a Lanby buoy moored at intermediate positions along sea paths in the English Channel. Annex 1 lists five UHF experiments between the UK and the Channel Islands or the French mainland, and two others which, although they contain some overland sections, are nominally regarded as oversea, because the intervening sea surface is visible from both transmitting and receiving antennas. Basic results for these experiments have been published^(4.16). Table 24 gives the details for the paths, comparing actual horizon ranges with those theoretically existing during average refraction conditions, i.e. 4/3 earth radius.

PATH	DISTANCE (km)	ANTENNA AMSL (m)		HORIZON RANGE (km)	
		Transmitter	Receiver	Actual	Av. Refrn.
Row ridge/Alderney	121	280	90	93	108
Row ridge/Torteval	167	280	80	90	106
Caradon Hill/Torteval	174	602	80	118	138
Stockland Hill/Alderney	137	461	90	110	128
Portland/Alderney	95	156	90	78	91
Row ridge/Digosville	110	280	220	112	130
Le Havre/Christchurch	193	189	22	66	76

TABLE 24
HORIZON RANGES FOR ENGLISH
CHANNEL LDR EXPERIMENTS

The shortest of these paths, from Portland to Alderney, provided results which can be compared with those in Figure 22, relating surface pressure to maximum daytime field strength levels. These appear in **Figure 25**, and although the effects of noise level were virtually absent on this shorter path, substantial scatter remains.

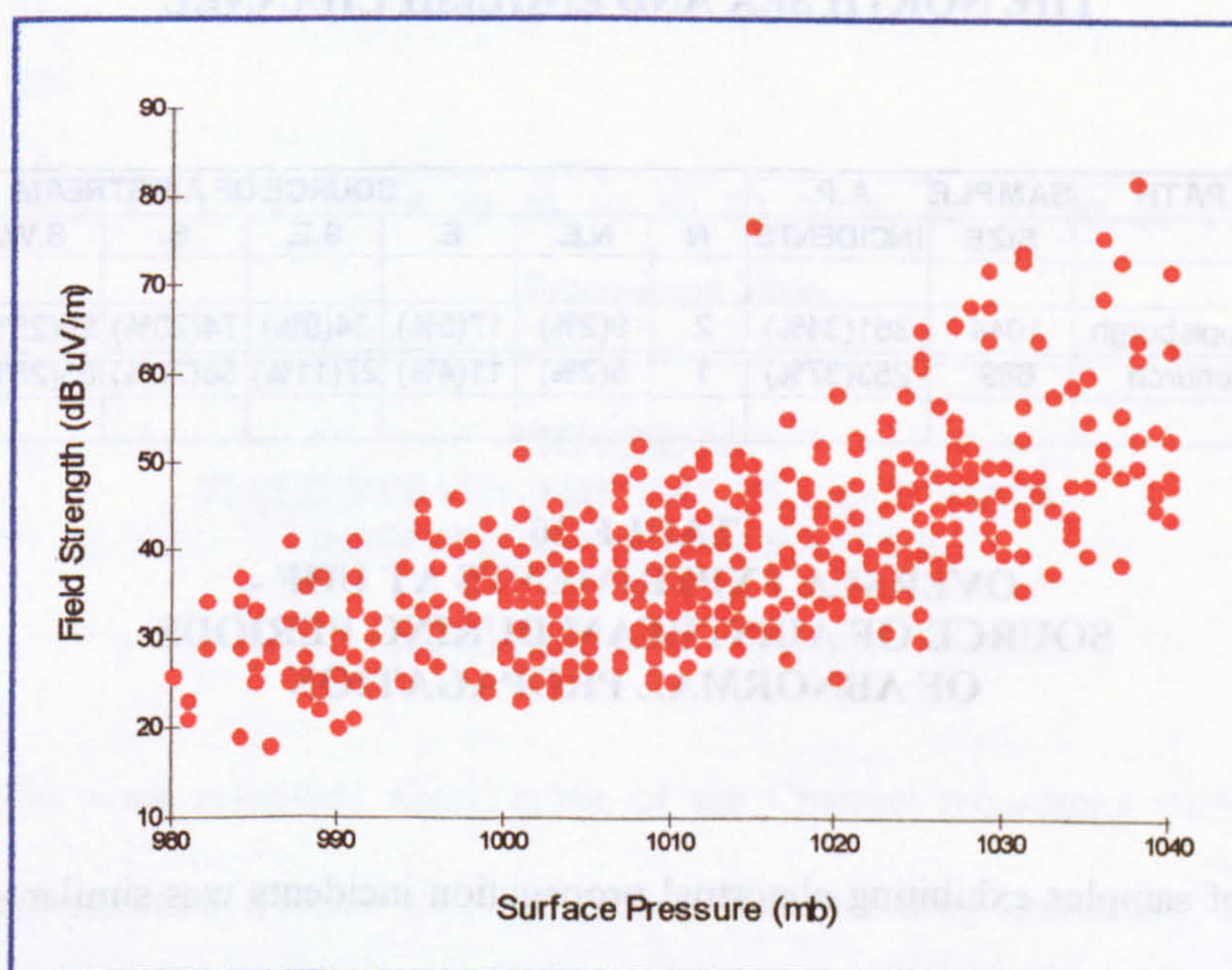


FIGURE 25
MAXIMUM DAYTIME FIELD STRENGTHS
RELATIVE TO SURFACE PRESSURES

Measurements made on 666 MHz on oversea path from
Portland to Alderney ERP = 1 kW

With regard to field strength/distance comparisons with the North Sea results, the experiment from Le Havre to the Christchurch receiver was informative because the path length of 193 km was

similar to that between Scheveningen and Happisburgh (198 km). Tables 25 and 26 show the analyses for these two paths, the first reporting the number of UHF measurement records available, and the second listing the airstream sources during the periods of abnormal propagation. The levels of field strength recorded during periods of abnormal propagation were highest on the longer path, the 1% time figure at Happisburgh being 65 dB μ compared with 59 dB μ at Christchurch, although it is noted the margin narrowed for the 5% time results to 46 dB μ and 45 dB μ , and the absolute maxima were very similar.

PROPAGATION PATH	YEAR	FREQUENCY (MHZ)	NUMBER OF PERIODS		DURATION (HRS)	
			DAY	NIGHT	DAY	NIGHT
Scheveningen - Happisburgh	1961	560	165	171	1460	842
Scheveningen - Happisburgh	1963	774	352	356	3298	1758
Le Havre - Christchurch	1969	653	342	347	2960	2435

TABLE 25
OVERSEA EXPERIMENTS AT UHF ACROSS
THE NORTH SEA AND ENGLISH CHANNEL

PROPAGATION PATH	SAMPLE SIZE	A.P. INCIDENTS	SOURCE OF AIRSTREAM							
			N	N.E	E	S.E	S.	S.W.	W.	N.W.
Scheveningen - Happisburgh	1044	361(34%)	2	9(2%)	17(5%)	34(9%)	74(20%)	92(25%)	113(31%)	20(5%)
Le Havre - Christchurch	689	253(37%)	1	5(2%)	11(4%)	27(11%)	56(22%)	65(25%)	71(28%)	17(7%)

TABLE 26
OVERSEA EXPERIMENTS AT UHF -
SOURCE OF AIRSTREAM DURING PERIODS
OF ABNORMAL PROPAGATION

The proportion of samples exhibiting abnormal propagation incidents was similar - about 34% in the North Sea and 37% in the Channel. Also, the contributions from the various airstreams were virtually identical, with about 80% of the total number of abnormal propagation incidents occurring during periods when the winds were in the favourable quadrant (south to west), and about 15% arriving from the east and south-east, mostly during the warmer months. The individual percentages are shown in parentheses. However, the overall range of field strength measured during each time period was generally lower in the Channel experiments, and originally this was attributed to the fact that transmitting antennas in these tests were higher than that used at

Scheveningen. A review of the detail suggests additional reasons. The screen of the UK mainland to the north, a generally warmer land mass to the south, higher sea and air temperatures, and marginally higher atmospheric pressures, combine to reduce tropospheric turbulence in the Channel area. Certainly the duration of periods of abnormal propagation during the UHF experiments was much longer than those measured in the North Sea, and also exceeded the VHF results by substantial margins (see later).

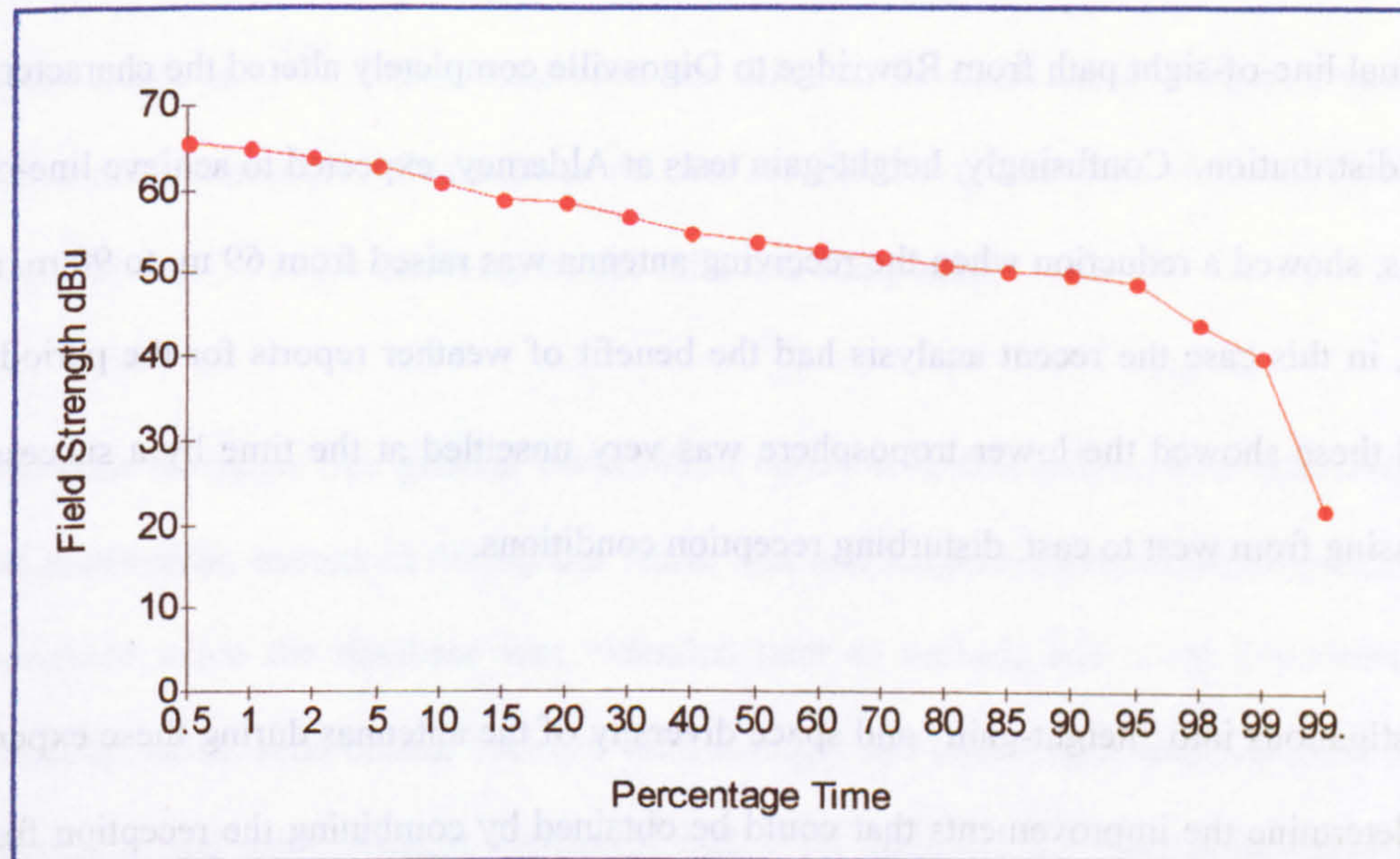


FIGURE 26
FIELD STRENGTH/PERCENTAGE TIME
ROWRIDGE TO DIGOSVILLE

(501.25 MHz ERP = 1 kW)

Because the paths were relatively short, some of the Channel recordings detected the second inflexion point referred to in Section 4.2., occasionally demonstrating almost total loss of signal. In particular, the length of the path between Rowridge and Digosville, on the Cherbourg Peninsular, a distance of 110 km, is virtually identical to the actual horizon range for the terminating antennas used in the experiment. As can be seen from Table 24, the terminals on this path are just within line of sight, and theoretically well within, given average refractive conditions. Recordings of reception show a near-normal distribution for up to 95% of each of the twelve-hour periods investigated. However, there were brief sessions of occasionally deep and very rapid fading,

caused by the tropospheric effects upon the horizon range. Figure 26 shows the field strength/percentage time graph for 180 12-hour periods for this path.

Horizon range was decisive in the onset of factors affecting the temporal distribution. Once exceeded, the nature of the curve could be positively correlated against surface weather conditions. Also, within the horizon, the range of temporal variation was generally less and the signal stronger during periods of high pressure, as mentioned at the beginning of this chapter. Thus the height of the terminating antennas could be critical. Measurements at different receiving antenna heights on the marginal line-of-sight path from Rowridge to Digosville completely altered the characteristic of temporal distribution. Confusingly, height-gain tests at Alderney, expected to achieve line-of-sight conditions, showed a reduction when the receiving antenna was raised from 69 m. to 90 m. a.m.s.l. However, in this case the recent analysis had the benefit of weather reports for the period of the tests, and these showed the lower troposphere was very unsettled at the time by a succession of fronts passing from west to east, disturbing reception conditions.

The investigations into "height-gain" and space diversity of the antennas during these experiments were to determine the improvements that could be obtained by combining the reception from two mounted at different heights. Over a period of time the height gain did not vary greatly in amplitude, and during incidents of abnormal propagation it virtually disappeared, unless it critically influenced the horizon range as mentioned above. Its real value was to offer some output from one of the antennas during "drop-outs", occurring at the other end of the time scale. Comparison of results obtained over a sea path from Italy to Sardinia^(4.17) revealed substantial improvements in the reduction of phase and amplitude distortions with the use of space diversity, and this technique has been widely used in service. However, each case is unique, and extensive testing has been required, theoretical studies based on path geometry have proved unreliable.

The effects of polarization were not extensively researched in the long-distance oversea experiments, and its rare mention in contemporary UHF reports undoubtedly led to the conclusion that it was largely irrelevant at these frequencies. However, this is a suspect outcome because VHF

measurements of vertically-polarized transmissions showed that during periods of abnormal propagation, higher values were reached by vertically-polarized transmissions, and the Portland/Alderney UHF experiment produced a similar result. For longer percentages of the time there was little difference between the two, although horizontal polarization was less prone to drop-outs. This tendency for the horizontally-polarized signal to undergo less variation in time over longer paths contrasts with its behaviour in the space domain. For example, although it concerns reflection from the earth's surface rather than refraction through the troposphere, it is relevant to refer to experiments over short stretches of water (< 20 km), to observe the effects of tidal changes and surface roughness^(4.18). These concluded that this was far more likely to be a serious problem with horizontal polarization, fluctuations of over 40 dB being observed in the received signal caused by interference to the direct ray by the reflected component.

It is important to report one general observation concerning the influence of path length upon temporal distribution measured during the North Sea and English Channel experiments, and this was confirmed when the database was extended later to include additional experiments. The simple concept of the relationship between field strength and path length was presented in Figure 19, and most of the measurements confirmed that at all distances the interdecile range generally produced a normal distribution. For shorter percentages of time, all the UHF overseas experiments produced maximum field strength values in excess of free space. The highest results were reached at the highest frequencies, thus in the example already quoted the maximum gain above free space of 20 dB was recorded on the Scheveningen – Happingburgh 774 MHz experiment (achieved for 48 minutes, representing about 0.015% of the total duration of the test). This maximum was achieved on a path length of about 200 km, and a further comparison using abnormal propagation measurements from other overseas experiments showed similar maxima occurred at intervals of approximately 200 km. Unfortunately the number of experiments available was small, and weather patterns seldom maintained abnormal propagation beyond 600 km, but the evidence was definite. Comparisons between the 1% and 5% time values and path lengths showed a similar coherence, with peaks at the same distances, although the pattern had virtually disappeared when the analysis was carried out for results representing longer percentages of time.

No in-depth attempt was made to pursue the observations concerning the behaviour reported in the previous paragraph, although the underlying simple path geometry was considered. With the terminating antennas in the experiments near sea level and with the highest values achieved at path lengths in the vicinity of 200 km, line-of-sight calculations suggest a principal reflecting surface at a height of about 3 km – the “stable troposphere” altitude. The series of high peak values suggested multiple, instantaneous in-phase refraction/reflection components, more likely because reflection losses at the sea surface points of re-radiation would be low. Reference to this form of “scatter” transmission appears in CCIR reports ^(2.10, 3.23), although it is difficult to find a clear definition. Some existing prediction processes assume that several transmission modes exist in isolation, even that the earth’s surface plays little or no part in the mechanisms. There is a long-standing concept that re-distribution of the energy back to the earth is caused by isotropic “blobs” (clouds?) of varying sizes within the troposphere. This seems reasonable for the long-term, low field strength situation, but the achievement of exceptionally high levels must demand rare conditions, capable of producing several in-phase refracted and/or reflected contributions - at least ten to reach the levels recorded during experiments at the highest frequencies.

The relatively uncomplicated oversea measurements supported reports by the radio amateurs ^(4.19, 4.20) that conditions conducive to abnormal propagation were more apparent on one side of a high pressure centre than on the opposite side. Within this “active” area, propagation over long distances occurred along paths which are aligned chordlike across the isobars, and there is some evidence that these chords are in line with the direction of movement of the centre of the system. With a much larger number of observations, the radio amateurs reported that the highest surface pressures were near the mid-point of the paths producing high field strengths, whilst pressures at the terminals were very similar. As the centre moved, the axes of the long paths changed to maintain the relationship.

The passage of weather centres and the examination of the recorded charts exposed another important feature, although its future impact was not appreciated at the time of the experiments. In contemporary reports it was customary to characterize the nature of signal fluctuation (which was

described as "fading"), as "Type 1 - little fading, Type 2 - low-frequency fading, and Type 3 - high-frequency fading". The first two were associated with reception during anticyclonic periods, whereas the third type occurred in cyclonic conditions. Type 3 was very seldom obvious over the longer paths, because it was usually below the noise levels of the receivers, but it was common at shorter distances. This behaviour was also distinctive during the build up and decay of an anticyclone, often with pressure below 1030 mb. In these circumstances the approaching centre would be heralded by a reduction in the amplitude and frequency of the fading range. In decline the sequence was reversed. During the early days of the LDR experiments the chart analysis was carried out manually, and it was common practice to record the mean value of these periods, which could persist for several hours. Thus the repetitive high and low peaks were often ignored in compiling the experiment statistics. Although this phenomenon was only of mild interest in analogue transmission, because rapid changes in the signal/noise ratio would pass largely unnoticed by the average viewer, the periodicity and depth of fading might be serious for fringe digital reception.

Most of the detailed analysis of oversea conditions in this project was based upon measurements made of propagation across the North Sea and the English Channel. There were few experiments across the seas to Ireland and other off-shore islands to the west and north of the mainland. Measurements made on the English coast of Band II transmissions from the Irish transmitter at Kippure near Dublin were reported ^(4.21), and comparisons with results from the North Sea experiments noted similar field strengths, although the Irish transmitting antenna was much higher than that at Scheveningen (813 m. a.m.s.l. compared with 59 m.). These results again demonstrated that whilst obviously the transmitting antenna determined the horizon range, once this had been exceeded it had little influence on abnormal field strength levels. Measurements in Ireland of transmissions from English and Welsh UHF transmitters confirmed normal reception levels and durations of periods of abnormal propagation across the Irish Sea were similar to those recorded across the English Channel. To the north west of the UK, measurements were restricted to tests for VHF and UHF links between the mainland and the Outer Hebrides, and records are inadequate for research purposes. The only reliable field strength measurements of transmissions from Norway

received in the UK were made at frequencies in the range 40 - 50 MHz, although an unpublished experiment by the IBA to determine the feasibility of linking Orkney and Shetland to the Scottish mainland provided some data concerning the rare occurrence of abnormal propagation in the north. Although warmed to some extent by the Gulf Stream, the sea temperatures are generally low, and the air streams are seldom stable. There were wide variations in the meteorological data at the time of the experiments, and stable propagation conditions in the south rarely extended to these areas.

Attention was next focused on overland and mixed paths. For the detailed study 38 experiments were selected from those listed in Annex 1, and Tables 27 and 28 show the number of days' recording for these paths, together with the total hours available for analysis.

TRANSMITTING AND RECEIVING SITES	YEAR	FREQUENCY (MHZ)	NUMBER OF PERIODS		DURATION (HRS)	
			DAY	NIGHT	DAY	NIGHT
Pontop Pike/Ottringham	1957	180.4	261	247	2281	1182
Pontop Pike/Ottringham	1957	560	233	216	1988	997
Pontop Pike/Dorset Head	1957	180.4	285	287	2410	1376
Pontop Pike/Dorset Head	1957	560	279	260	2398	1210
Pontop Pike/Mursley	1957	180.4	272	277	2372	1304
Pontop Pike/Mursley	1957	560	281	274	2415	1319
Pontop Pike/Kingswood	1957	180.4	213	215	1814	1004
Pontop Pike/Kingswood	1957	560	221	215	1891	998
Pontop Pike/Beddington	1957	180.4	258	247	2221	1148
Pontop Pike/Beddington	1957	560	270	265	2293	1261
Crystal Palace/Caversham	1961/2	41.5	197	194	1741	1433
Sutton Coldfield/Caversham	1961/2	58.25	185	187	1850	1501
Sutton Coldfield/Caversham	1961/2	88.3	172	183	1830	1545
Wenvoe/Caversham	1961/2	63.25	177	175	1695	1539
Wenvoe/Caversham	1961/2	89.95	181	178	1821	1214
Peterborough/Caversham	1961	63.27	185	183	1904	1582
Peterborough/Caversham	1961	90.1	180	187	1765	1626
N.Hessary Tor/Mursley	1961/2	48.23	146	151	1528	914
N.Hessary Tor/Mursley	1961/2	88.1	150	138	1485	843
Crystal Palace/Mursley	1961/2	41.5	203	197	1894	1311
Sutton Coldfield/Mursley	1961/2	58.25	199	205	1903	1105
Sutton Coldfield/Mursley	1961/2	88.3	201	175	1917	938
Wenvoe/Mursley	1961	63.25	178	184	1822	1007
Wenvoe/Mursley	1961	89.95	172	180	1720	1119
Wrotham/Caversham	1961/2	89.1	200	194	1944	1641
Row ridge/Mursley	1961/2	88.5	187	192	1885	1138
TOTALS			5216	5406	50787	32255

TABLE 27
DETAILS OF OVERLAND LDR EXPERIMENTS

As with the overseas paths, the correlation between surface pressure and field strength was

examined first, and reached similar conclusions to those already described. The overall situation was generally confused, reproducing graphs with even greater scatter than that shown in Figure 22. The rate of decay of field strength on overland sections was also relatively high, so the effects of receiver noise level again often distorted the overall assessment.

In common with the overseas investigations below 100 MHz, the characteristic inflexion point associated with abnormal propagation rarely appeared in the field-strength distributions for each twelve-hour period. Of the overland periods measured at frequencies above 100 MHz, about 7% of the graphs contained a point of inflexion, compared with the equivalent figure of 15% for the North Sea paths.

PROPAGATION PATH	YEAR	FREQUENCY (MHZ)	NUMBER OF PERIODS		DURATION (HRS)	
			DAY	NIGHT	DAY	NIGHT
Scheveningen to Happisburgh	1963/64	560	214	187	1622	903
Scheveningen to Tacolneston	1963/64	560	198	190	1668	921
Scheveningen to Feltham	1963/64	560	203	192	1647	934
Scheveningen to Peterborough	1963/64	560	222	199	1731	947
Scheveningen to Skeffington	1963/64	560	197	180	1680	842
Scheveningen to Bawdsey	1966	774	302	291	3018	720
Scheveningen to Manningtree	1966	774	311	303	3005	814
Scheveningen to Brookmans Park	1966	774	129	129	1303	421
Scheveningen to Hatfield	1966	774	227	203	2310	590
Scheveningen to Kingswood	1966	774	205	211	2170	625
Scheveningen to Caversham	1965	774	102	48	1090	109
Le Havre to Kingswood	1968/70	653	230	221	2004	650
TOTALS			2540	2354	23248	8476

TABLE 28
DETAILS OF MIXED-PATH EXPERIMENTS

In general, observations during this phase of the study concerning the relationships between meteorological factors and field strength results endorsed most of those made earlier although the overland topographical features introduced many detailed local variations. With regard to diffraction, for example, the weather data showed that the direction of an airstream across a diffraction edge could affect the temporal distribution of field strength at a receiving site screened by the edge. Similarly, during periods of abnormal propagation, diffraction losses were less than those measured in normal conditions, an important feature which also influenced the temporal

range of the received signal, and which is discussed in more detail below. Although the effects upon propagation of major shifts in weather movements could certainly be observed, the fading patterns overland were often much more dynamic than those recorded on oversea paths, and underlined the value of local meteorological information.

The overland experiments offered the opportunity to examine the simultaneous measurements at single receiving sites of signals incoming from different directions, revealing the correlation in time between those signals, and between the meteorological data along their propagation paths. This provided useful information concerning the application of the airstream data, confirming the generally stabilizing effect of winds coming from the south-western quadrant.

Concerning the relationship between path length and field strength levels, on the oversea paths it was reported earlier that the maximum contribution by way of refraction/reflection from the troposphere occurred at path length intervals of about 200 km. It was suggested this could be produced by reflecting/refracting entities about 3 km above the surface of the sea. Inspection of the overland paths indicated a similar tendency at about 200 km, although the number of experiments was small, with very few beyond this distance. Again the feature was most evident at the higher frequencies, but the cyclic behaviour overland was more confused by the geometry of the path, and dependent upon the height of the intervening terrain. There was also another distinct difference, namely that whereas in the oversea case free space field strengths were exceeded by substantial margins on a number of occasions, this phenomenon was very rarely recorded during the overland experiments.

It is relevant to mention a recent and extensive LDR experiment that was conducted during the period 1995 – 97, although measurement details were not available for this project ^(4.22). Reception was recorded at a single point (Daventry) of transmissions in Bands III and V from five transmitters, involving overland path lengths from 150 to 300 km. A sixth path over a distance of 633 km was also measured, but these results were regarded as insignificant. The measurements showed that current prediction methods substantially underestimated signal levels reached during

periods of abnormal propagation, the 1% time error being in the range of 10 - 20 dB. Interestingly, the report presented an alternative view of the discrepancies, namely that the predicted 1% time levels actually occurred for between 4% and 6% of the time.

In the case of mixed land/sea paths, if the meteorological conditions on the oversea section extended over the land, then the rate of decay of field strength with distance did not significantly increase if the surface was flat. Comparisons against measurements from other warmer regions in the world where the meteorological conditions are less confused and coastal areas are very flat provided clearer demonstrations of this feature. However, even brief diurnal periods of local wind change caused, for example, by warm air flowing off the land over the sea, could create a transitory barrier that completely changed the characteristics of the propagation over the land section of the path. The risk of this occurring in north-west Europe was lowest during the turbulent periods between late October and mid-March. As the distance from the coast increased, or the terrain changed, the rate of field strength decay increased, unless the antenna was high enough to remain within line of sight of the sea surface. Persistent comments were made in contemporary reports that the internationally-recommended method of mixed-path prediction became increasingly unreliable as the distance from the coast increased. Recent calculations using the listed results confirmed this, although much depended upon the time value chosen, the errors being greatest for the short-percentage time predictions. Persistently, short-percentage time values were least affected by terrain undulations, and this factor concentrated attention on the method that had been used to obtain the SVF corrections. This was clearly important, because this would impact upon the published experimental results.

Described in Chapter 2, the SVF adjustments had been made to LDR experimental results to represent "50% location" conditions, in keeping with the shorter distance measurements. The correction technique assumed long-term temporal changes in signals received from a distant transmitter would be identical, both in time and in amplitude, at all receiving sites within a small area about 20 km in diameter. There were contemporary criticisms of this assumption, and in the light of these and the many disparities that emerged during the course of this project, the feature

was thoroughly explored.

SVF results for 33 LDR experiments were re-examined, each of which included about 20 short-term measurements made in the country surrounding the main reception site, in effect reproducing a macroscopic distribution for each of the 33 areas. Terrain clearance angles were obtained for each measurement site (an actual total of 622), but attempts to use the single 50% time/50% location TCA correction curve to quantify the spatial effect of the immediate foreground failed - the adjustment varied with time. Very convincing evidence was obtained from experiments where chart recordings of the signals at SVF sites were compared with simultaneous sections of the recordings made at the main LDR receiver, often revealing quite different signal patterns. This suggested a link back to spatial distribution, because if some form of time-variable TCA adjustment to quantify the influence of terrain upon each microscopic cell could be devised, the distinction between temporal ranges for adjacent cells might be exposed.

Generally, during the periods of abnormal propagation there was relatively little difference between the field strengths at exposed or shielded sites, supporting the original assumption, and this feature was especially apparent at higher frequencies. In contrast, for lower time percentages, the diffraction effect of local terrain was much more obvious, and greater losses were recorded at the screened sites, tending towards the conventional TCA correction originally based upon short-range 50% time/50% location results.

In Figure 27, SVF measurements at a few sites have been separated to show the distinction between those made during normal and abnormal propagation conditions. It demonstrates the likely extent of corrections to be made to the temporal range measured at the main fixed receiver, taking into account the local variations in terrain and ground cover. The exposed main sites almost without exception had a positive angle, and the temporal ranges of signal recorded at these were relatively limited when compared with those measured at the local SVF sites where the receiving antenna was screened. Each test location was unique, and required its own SVF adjustment to be derived from the measurements by comparison with the simultaneous result at the main site. The

UHF tests revealed the greatest differences, although receiver noise levels often obscured the real attenuation. A significantly different assessment of the distribution of the interfering signal emerged, which supported contemporary reports that the practical effects upon the majority of viewers of interference was likely to be quite different from those predicted.

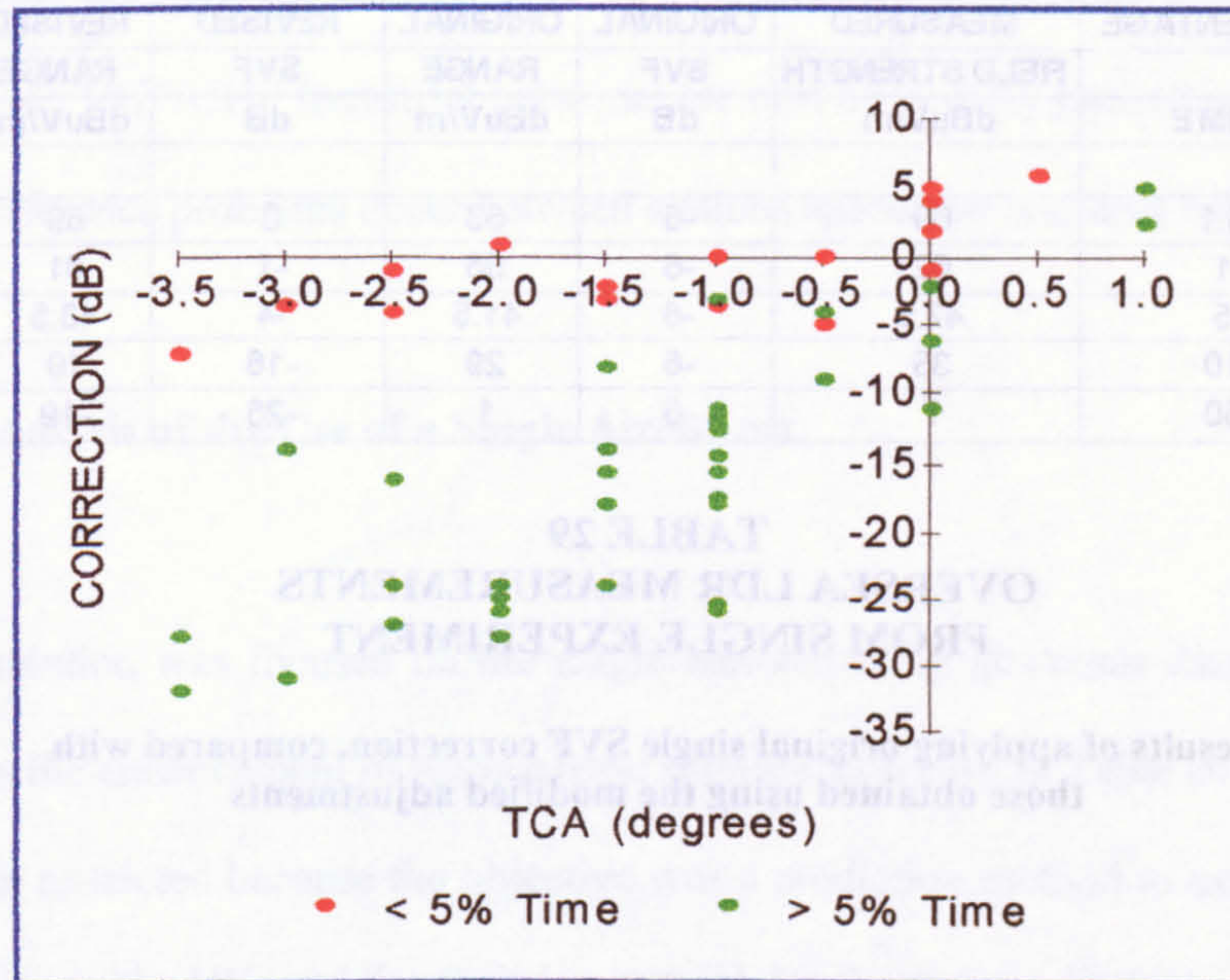


FIGURE 27
TERRAIN CLEARANCE ANGLE – INFLUENCE OF
ABNORMAL PROPAGATION

Site variation factor measurements recorded during periods of abnormal propagation show attenuation caused by local terrain is less than that during normal conditions

The last point is important, and underlines the effect that these findings would have upon the experimental results, which in turn would affect the whole basis of the planning data. Because the majority of the population lived in areas having negative terrain clearance angles, the temporal range of the interfering signal was likely to be much greater than that predicted. Abnormal propagation levels in many cases would have been underestimated in the planning calculations whilst the risk of interference during normal conditions was likely to have been overestimated. Tables 29 and 30 are examples of oversea and overland paths which illustrate the extent of change. Each table shows the measured range of the field strength at a particular site, which has then been corrected by the single SVF value obtained at the time of the experiments to produce the original

estimate of the temporal range, listed in the fourth column. Results such as these were the evidence for the original field strength/distance curves. This range should be compared with that shown in the sixth column, obtained by correcting the original measurements using the revised SVF values. The short-percentage time figures have increased, whilst the longer periods have decreased.

PERCENTAGE	MEASURED	ORIGINAL	ORIGINAL	REVISED	REVISED
	FIELD STRENGTH	SVF	RANGE	SVF	RANGE
TIME	dBuV/m	dB	dBuV/m	dB	dBuV/m
0.1	69	-6	63	0	69
1	62	-6	56	-1	61
5	47.5	-6	41.5	-4	43.5
10	35	-6	29	-16	19
50	7	-6	1	-26	-19

TABLE 29
OVERSEA LDR MEASUREMENTS
FROM SINGLE EXPERIMENT

Results of applying original single SVF correction, compared with those obtained using the modified adjustments

PERCENTAGE	MEASURED	ORIGINAL	ORIGINAL	REVISED	REVISED
	FIELD STRENGTH	SVF	RANGE	SVF	RANGE
TIME	dBuV/m	dB	dBuV/m	dB	dBuV/m
0.1	65	-7.5	57.5	1	66
1	47	-7.5	39.5	-4	43
5	31.5	-7.5	24	-7	24.5
10	24.5	-7.5	17	-22	2.5
50	-3	-7.5	-10.5	-36	-39

TABLE 30
OVERLAND LDR MEASUREMENTS
FROM SINGLE EXPERIMENT

Results of applying original single SVF correction, compared with those obtained using the modified adjustments

Following this investigation, all the UK LDR records were re-examined, and revised SVF corrections were made to many of the results. These adjusted measurements, and not those in the early records, were used in the development of the revised prediction described later.

In summary, the detailed surface weather reports provided valuable new evidence. Perhaps most

significantly, the study confirmed the importance of the nature of airstreams in explaining the stability of the troposphere and the incidence of abnormal propagation. From this information, many interdependent statistics were deduced which could have formed the basis of a very comprehensive field strength prediction model. However, much further research would have been needed, so for the restricted objectives of this project a simpler solution based on the airstream data was adopted. This meant some detail would be lost, and the risk of error would increase with distance. However, VHF/UHF terrestrial networks are now so densely packed in Europe that more than 98% of interference problems occur between stations spaced by less than 500 km.

4.4.3. The Analysis of the Use of a Single Airstream

In this phase, attention was focused on the single national daily airstream data ^(4.13), modified to concentrate upon the enhancement of tropospheric stability as shown in Table 20. The scope of the investigation was restricted because the objective was a prediction method to examine the existing television coverage in the UK, and the digital terrestrial developments. Both are in the UHF bands, so further research was concentrated upon these frequencies. The measurements used were 53 UHF experiments selected from Annex 1, and 39 UHF results from other LDR experiments not so far included, listed in Annex 2 (both Annexes appear at the end of this chapter). The approximate geographical distribution of the overland propagation paths measured by these experiments is shown in Figure 28, whilst the oversea and mixed paths, appear in Figure 29. In both figures, some distortion in the positioning of details has been inevitable to assist clarity.

The preceding detailed examination had revealed that abnormal propagation was most likely to occur when the airstream originated from the south-westerly quadrant, although some contributions could also be expected during the summer months from the south east. The results of a comparison using the revised airstream categories and the field strength measurements from the 92 UHF experiments, are shown in Table 31. This lists the total numbers of periods measured and the incidents of abnormal propagation, the latter as percentages of each total subdivided under the 11 airstream sources likely to produce increased tropospheric stability, already identified in Table 20.

TRANSMITTERS

- A Crystal Palace
- B Sutton Coldfield
- C Pontop Pike
- D Holme Moss
- E Belowda

RECEIVERS

- | | |
|------------------|--------------------|
| 1 Caversham | 16 Aldeburgh |
| 2 Mursley | 17 Banbury |
| 3 Ottringham | 18 Saw on the Wold |
| 4 Dorket Head | 19 Shrivenham |
| 5 Kingswood | 20 Peatling Magna |
| 6 Beddington | 21 Halwell |
| 7 Dishforth | 22 Great Baddow |
| 8 Moonside Edge | 23 Brookman's Park |
| 9 Bawdsey | 24 Hatfield |
| 10 Manningtree | 25 Darlington |
| 11 Peterborough | 26 Cratkeon |
| 12 Tacolneston | 27 Slough |
| 13 Sunning Hill | 28 Widley |
| 14 East Harptree | 29 West Beckham |
| 15 Bentley | |



FIGURE 28
UHF OVERLAND LDR EXPERIMENTS

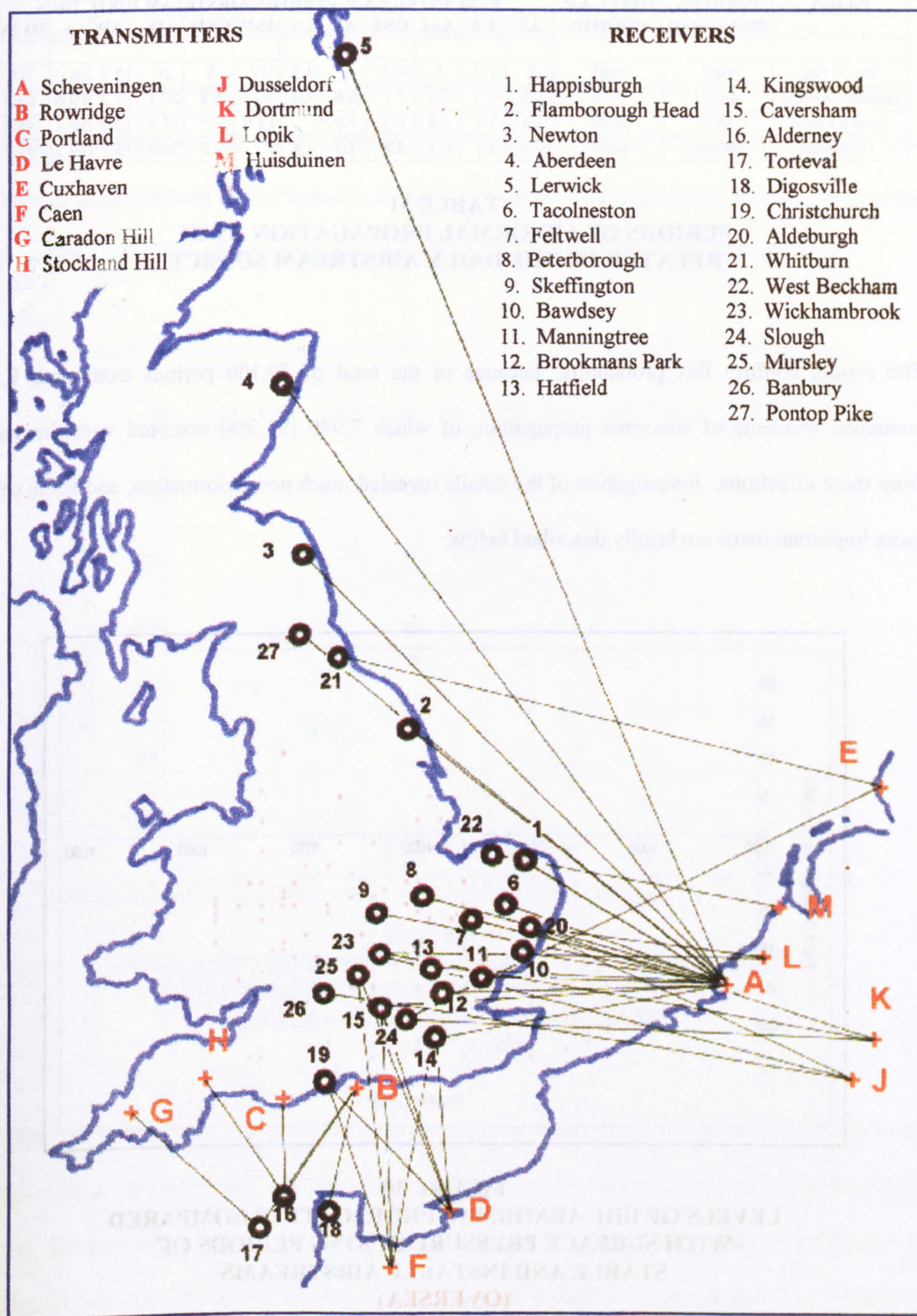


FIGURE 29
OVERSEA AND MIXED PATH UHF LDR EXPERIMENTS

PATHS	PERIODS	TOTAL A.P. PERIODS	PERCENTAGE A.P. PERIODS/AIRSTREAM DIRECTION											
	MEASURED		AE	CE	ASE	CSE	AS	CS	ASW	CSW	AW	ANW	A	TOTAL
North Sea	9662	3285	2	1.3	5	6.4	7	3.5	17	5	19	12.2	18.6	97
English Channel	4524	1673	2.3	0.9	7.2	7.1	8.8	3.4	6.9	5.8	20.1	13.2	19.6	95.3
Mixed Paths	14856	2079	2.1	1.1	5.8	6.7	7.9	3.6	13.9	4.9	17.4	12.8	19.4	95.6
Overland	10064	1207	0.3	1.7	6.1	4.8	7.3	1.8	17.4	4.7	20.3	13.7	19.1	97.2

TABLE 31
PERIODS OF ABNORMAL PROPAGATION AT UHF
RELATED TO THE DAILY AIRSTREAM SOURCE

The results confirm this probability, because of the total of 39,106 periods examined, 8,244 contained incidents of abnormal propagation, of which 7,940 (96.3%) occurred with the winds from these directions. Investigation of the details revealed much new information, and some of the more important items are briefly described below.

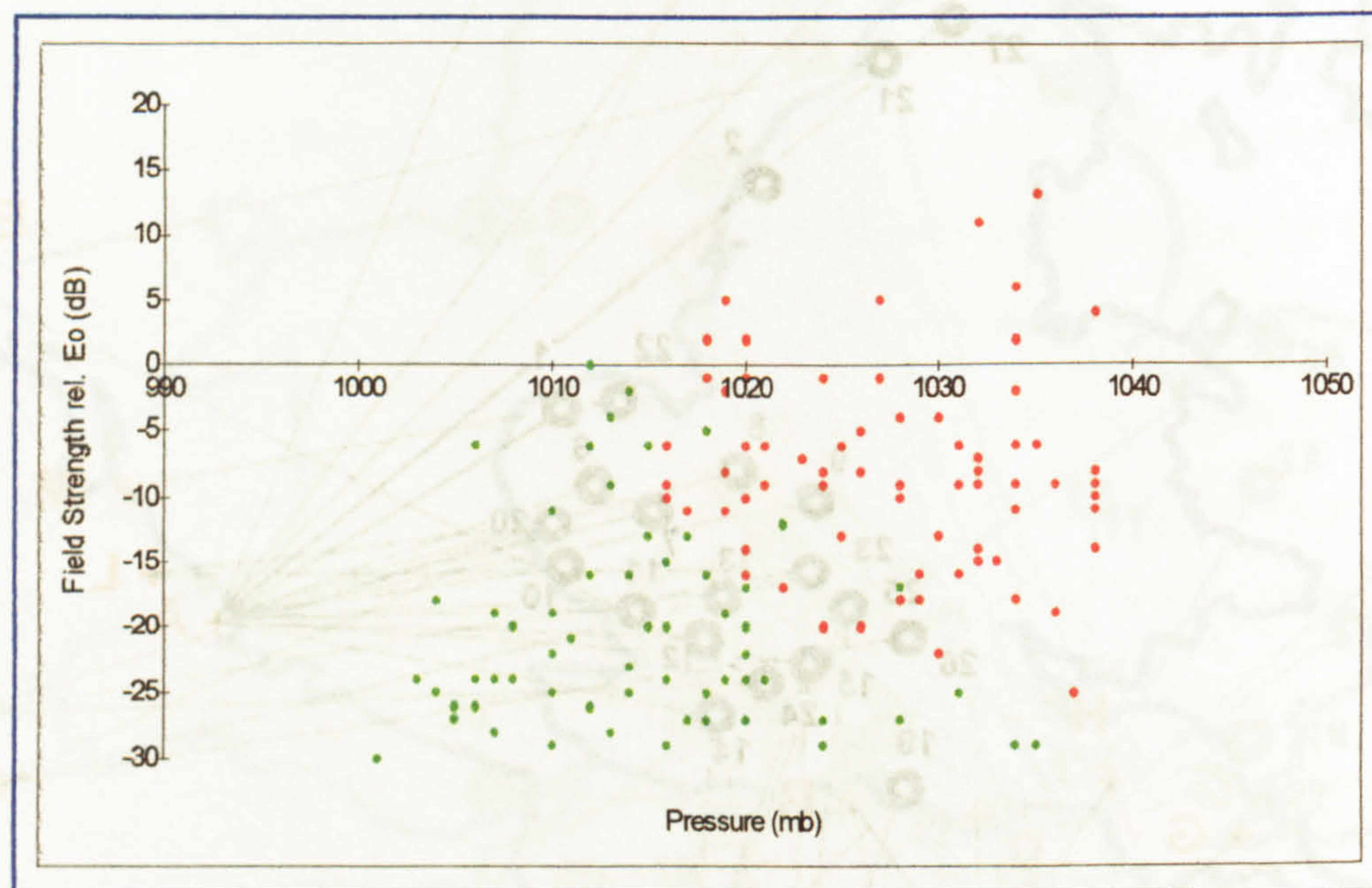


FIGURE 30
LEVELS OF UHF ABNORMAL PROPAGATION COMPARED
WITH SURFACE PRESSURE DURING PERIODS OF
STABLE AND INSTABLE AIRSTREAMS
(OVERSEA)

Figures 30 and 31 show typical results regarding the highest levels of field strength reached, the first for oversea paths, the second for overland. Maximum field strengths, relative to the free space (E_0) value for each path have been plotted against the daily surface pressure, and the graphs

distinguish between measurements made when the airstreams were classed as “stable” (red plots) or “instable” (green). The results confirm that tropospheric stability is likely to accompany high surface pressure, and the highest field strengths were reached when this occurred during stable tropospheric conditions, although at levels lower than the 1030mb previously assumed. The substantial scatter in both these Figures is attributed to the use of a single daily airstream to analyse the situation – the distributions could be substantially reduced by using the six-hourly data.

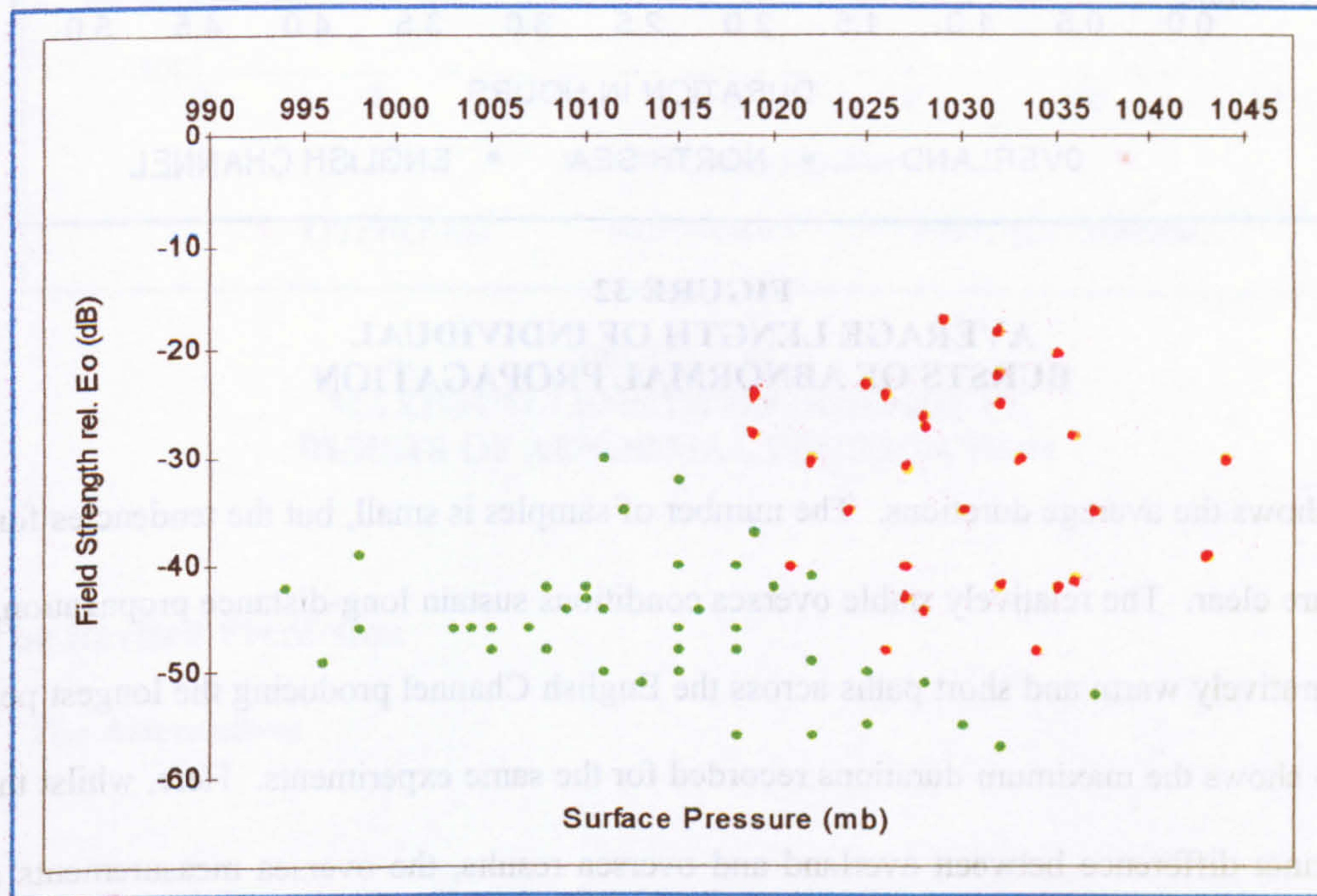


FIGURE 31
LEVELS OF UHF ABNORMAL PROPAGATION COMPARED
WITH SURFACE PRESSURE DURING PERIODS OF
STABLE AND INSTABLE AIRSTREAMS
(OVERLAND)

The duration of *individual* bursts of abnormal propagation is also important because it is a factor in the perception of interference, and hence in the prediction of coverage. As previously described, the risk of interference is assessed on the field strength level reached for a defined percentage of the overall time, say 1% or 5%, but the value reported in typical propagation curves is the sum of several bursts of signal, each of varying duration. The average and maximum lengths of abnormal propagation occurring during twelve-hour periods were derived, and these results are shown in Figures 32 and 33.

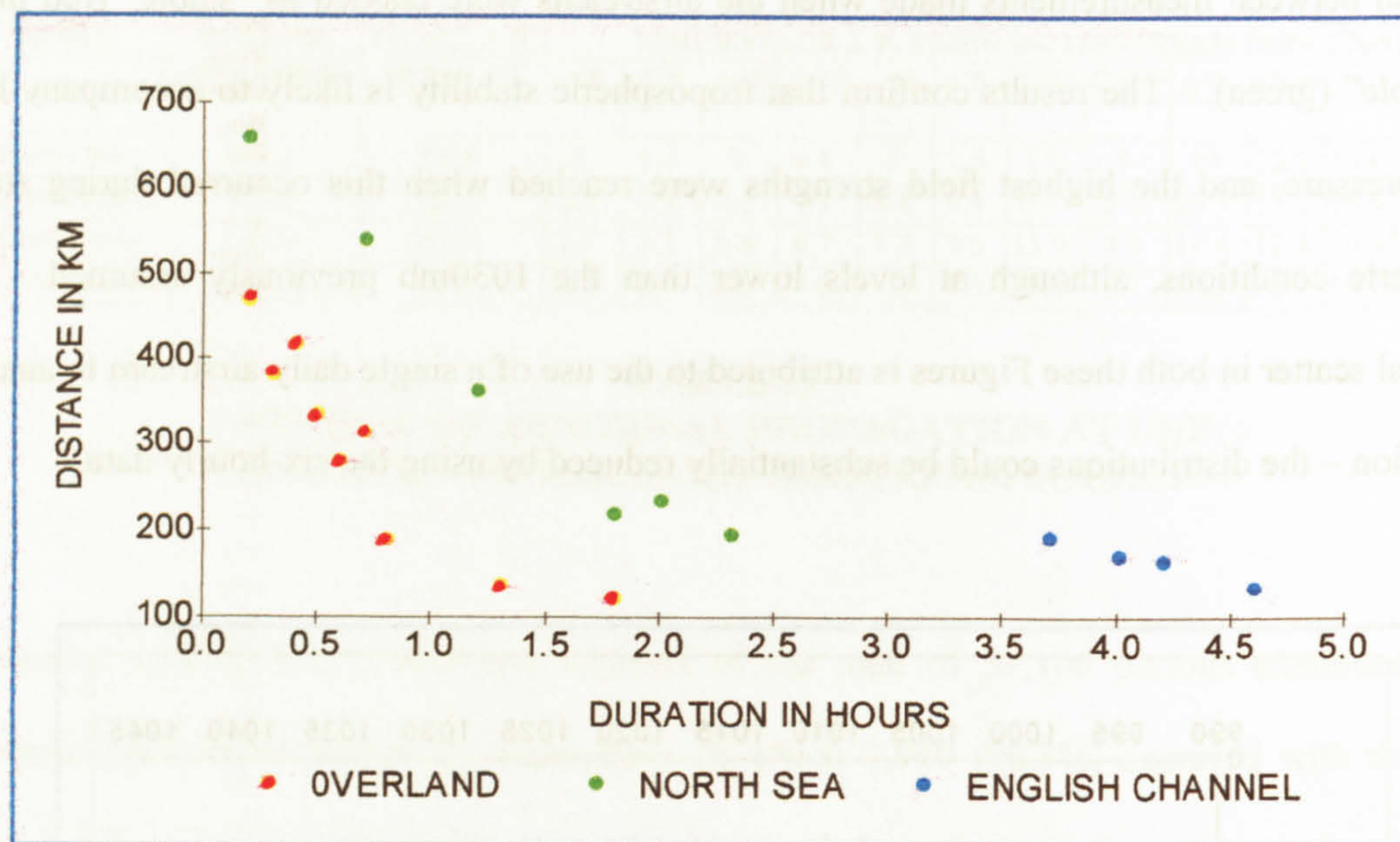


FIGURE 32
AVERAGE LENGTH OF INDIVIDUAL
BURSTS OF ABNORMAL PROPAGATION

The first shows the average durations. The number of samples is small, but the tendencies for each situation are clear. The relatively stable overseas conditions sustain long-distance propagation, with the comparatively warm and short paths across the English Channel producing the longest periods.

Figure 33 shows the maximum durations recorded for the same experiments. Here, whilst there is still a distinct difference between overland and overseas results, the overseas measurements at the shortest ranges are similar. Again the measurements demonstrated the influence of frequency - with all of the maxima coming from results recorded during experiments at the upper end of the UHF band.

Whereas the study based upon detailed surface meteorological records had helped to interpret the relationships between tropospheric states and field strength measurements, the results from the single airstream analysis showed that this was also a reasonable guide to the incidence of abnormal propagation, certainly at the higher frequencies. It lacked the detailed short-term precision which could only be achieved with the meteorological data, but it produced valuable statistics concerning abnormal propagation over a long period of time. It is now described how, together with the earlier evidence, this provided the basis for the development of a revised prediction program.

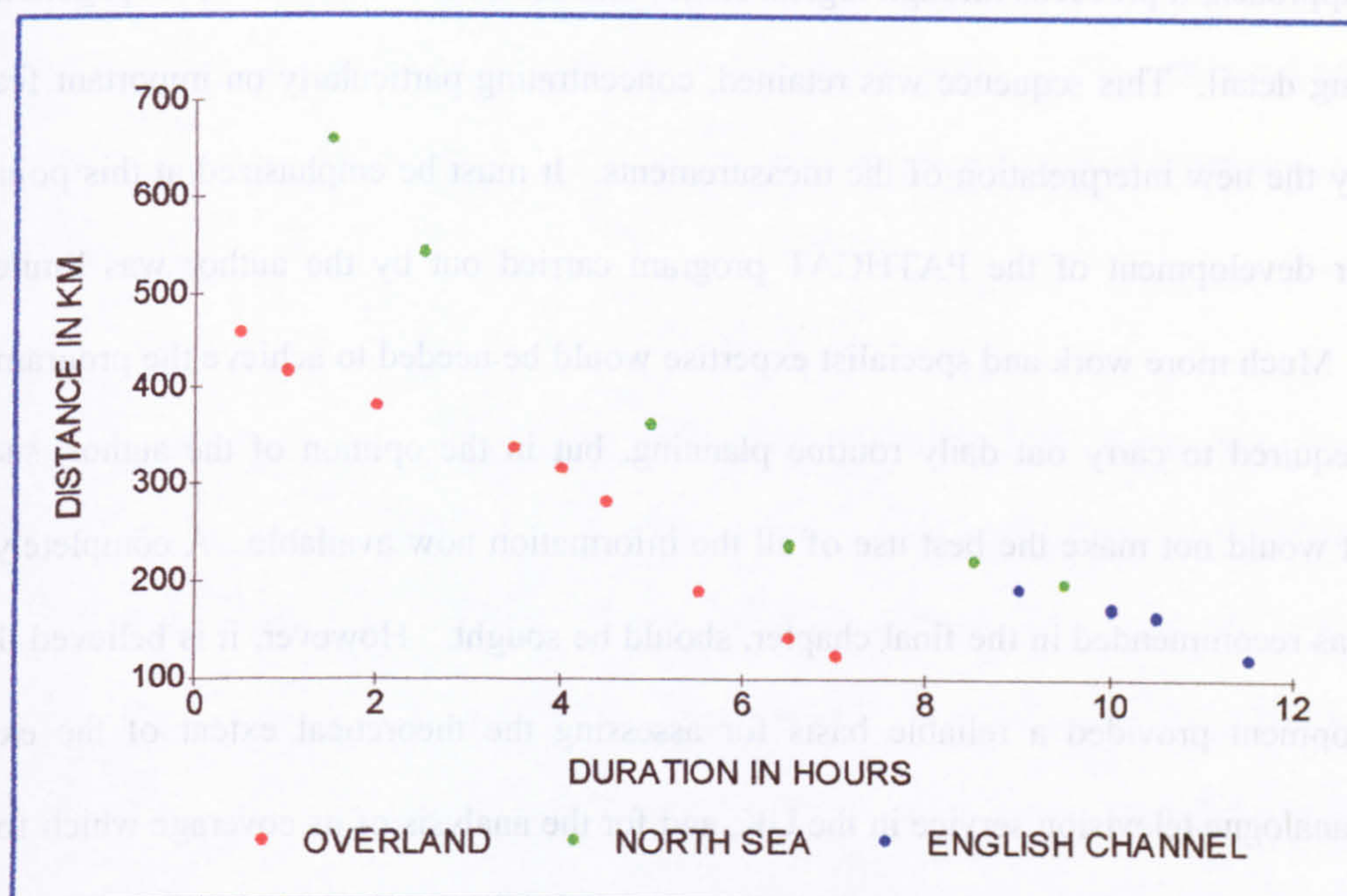


FIGURE 33
MAXIMUM LENGTH OF INDIVIDUAL
BURSTS OF ABNORMAL PROPAGATION

4.5. The Revised Prediction

4.5.1. The Alternatives

Various prediction methods described in Chapter 3 were considered. Currently, a great deal of international effort is devoted to developing the CCIR/ITU method, and a demanding timescale has been imposed. The ITU objective is to seek a planning method that will allow new frequency assignments to be agreed for the whole of the European area, and certainly attempts at this critical stage to inject suggestions involving quite radical changes to widely accepted methods would be most unwelcome. It is also accepted that whilst the author remains convinced that the international method contains inherent shortcomings, it is capable of providing results which can demonstrate whether or not successive planning proposals achieve improvements. The scope of the project described in this thesis was initially more conservative, aiming to quantify the real quality of present reception in the UK. Therefore it was decided to develop the PATHCAT program, which, as mentioned in Chapter 3, had been originally proposed by the author. There was substantial evidence to support its use within the limits of the UHF broadcasting bands, and although it is an

empirical approach, it proceeds through logical stages that define the nature of the propagation path in increasing detail. This sequence was retained, concentrating particularly on important features revealed by the new interpretation of the measurements. It must be emphasized at this point that this further development of the PATHCAT program carried out by the author was limited by resources. Much more work and specialist expertise would be needed to achieve the programming standard required to carry out daily routine planning, but in the opinion of the author, such an investment would not make the best use of all the information now available. A completely new approach, as recommended in the final chapter, should be sought. However, it is believed this ad hoc development provided a reliable basis for assessing the theoretical extent of the existing terrestrial analogue television service in the UK, and for the analysis of its coverage which follows in the next chapter.

4.5.2. Development of the PATHCAT Prediction

The work began with the re-analysis of the field strength measurements so that they conformed to the time and space standards devised for this project. Wherever possible, the short-range results were adjusted so that they represented median values of the location distribution within a 100 m. square in a rural area. However, more radical modifications were needed for the results from the LDR experiments, and these were based upon the airstream analysis shown in Table 20.

A detailed study of the weather reports issued for the period 1940 – 1971 confirmed that a potentially stabilizing airflow existed over the UK area for about 43% of the time. This is less than the estimate of “more than 50%” quoted earlier because the closer study clarified the summer contribution of winds from the eastern quadrant, and overlaps between anticyclonic contributions. Importantly, detailed comparison with the LDR measurements confirmed that field strengths only reached their highest levels as the surface pressure approached 1030 mb, and the data showed that the probability of this occurring escalated when favourable winds had persisted for seven days or more. It was decided, therefore, that measurements to be used in the construction of the LDR curves would only be taken from those days. Of course this means that the “time percentage”

measure now has a totally different base from that used previously, because it is now derived from less than 20% of the available measurements, the fraction most affected by abnormal propagation. This decision was taken after considering reports of the public perception of interference, described in the next chapter.

Over the 32 years there were 265 periods, each consisting of at least seven days, during which these winds persisted. Unfortunately the detailed LDR experiments were restricted to the years between 1954 and 1971, so the study was limited to 123 periods, which together contained a total of 1,120 days. In fact, the weather data for the preceding years provided some additional statistics concerning the long-term behaviour of the troposphere. Apart from isolated experiments by various organizations, the author also had access to early operational reports from 60 Group RAF describing reception conditions during the Forties. These related to air/ground communication around 120 MHz, where abnormal propagation is less apparent. Nevertheless several records of reported "crosstalk" were positively identified as occurring during periods when the airstream reports suggested tropospheric conditions were favourable.

The daily analyses of the LDR measurements made during the 1,120 days were used to prepare overland and oversea field strength/distance curves for three time percentages - 1.0%, 10.0% and 50.0%. These were corrected to represent the 50% location datum using a revised SVF adjustment, in the form outlined in Figure 27.

With regard to frequency, the data suggested five sets of curves centred upon 50 MHz, 100 MHz, 200 MHz, 500 MHz and 1000 MHz. However, the first two were complicated by problems concerning ground reflection and polarization, and full analysis of all the results would have taken some time. Furthermore, as the immediate interest in this project was in the existing television bands, action on the VHF measurements is not described here, although they provided useful supplementary data. Thus the development concentrated on a prediction technique to deal with UHF, assuming a centre frequency of 600 MHz. Propitiously the new CCIR/ITU draft issued in 2002 to supersede Recommendation 370 also specifies this frequency ^(4.23). It is understood this

new recommendation, containing some propagation curves which are substantially similar to the 1966 edition of Recommendation 370^(1.79), is to be used for future international planning, so comparisons between the various issues of the CCIR/ITU document will be possible.

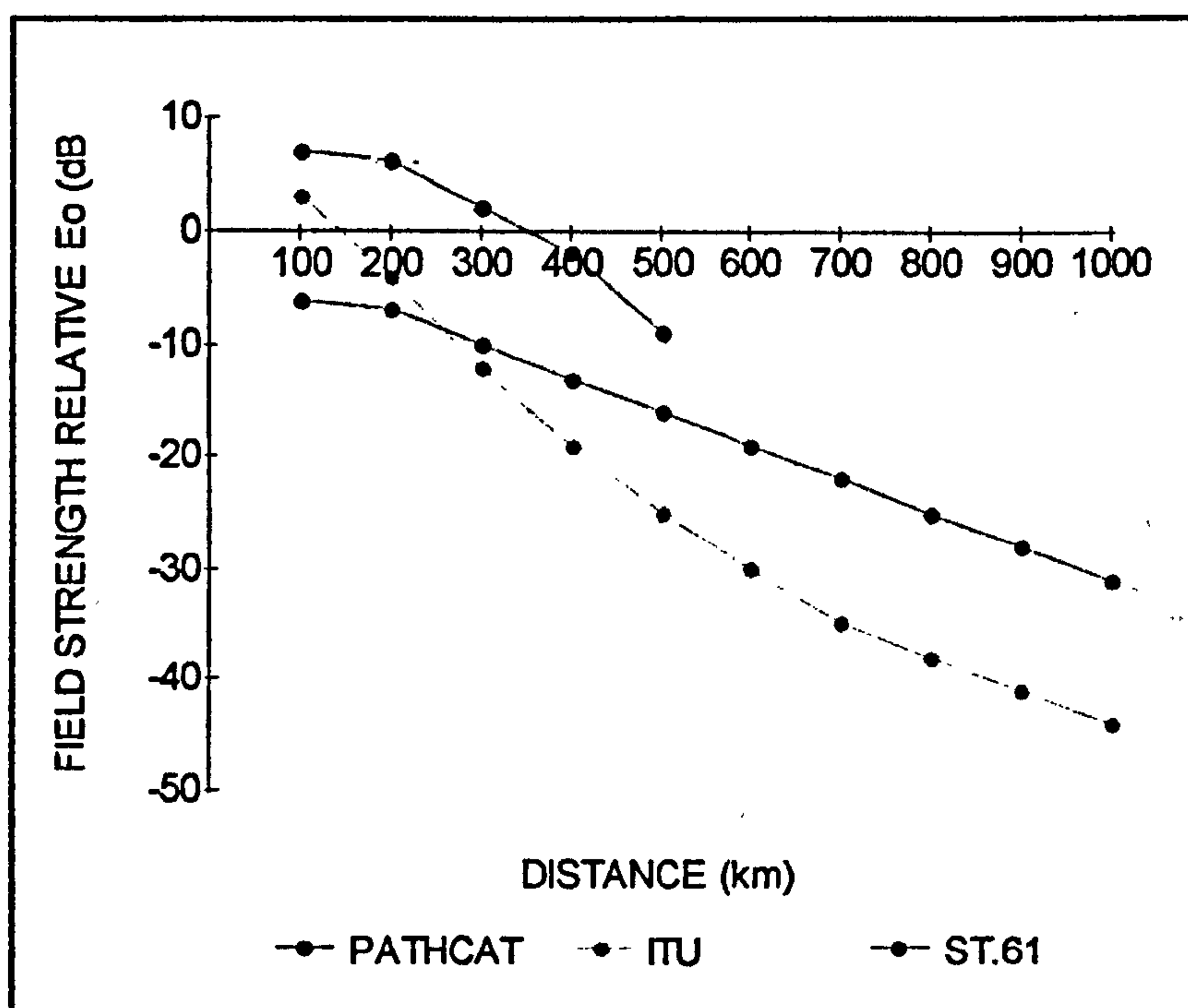


FIGURE 34
FIELD STRENGTH/DISTANCE CURVES
600 MHz OVER COLD SEA - 1% TIME

Examples of the revised PATHCAT version and the propagation curves prescribed for international UHF planning, i.e. those prepared for the Stockholm Conference (ST.61), and the 1966 Recommendation 370 (ITU) replacement which was used for development after that year, are compared in Figure 34. This shows the 1% time (cool sea) curves. As mentioned above, it is believed that the Recommendation 370 curve is substantially similar (for distances beyond 100 km) to that contained in the latest ITU draft. The main reason for the substantial increase in the PATHCAT notional 1% time curve compared with the other results, is the application of the modified SVF correction. It is considered that the decision to use only those measurements made during extended periods of abnormal propagation in the derivation of these curves can be reliably equated to public reaction to reception quality, as mentioned above. The PATHCAT results were not extended beyond 500 km because of the unreliability of the interpretation of the measurements

beyond this distance, and the subsequent interference and coverage analyses conducted in this project did not include longer ranges.

No attempt was made to refine the definition of the antenna height in the revised prediction, although this had been a source of contention when the earlier PATHCAT proposals were presented. Examination of the measurements confirmed the arguments against the use of the effective height technique, and at UHF, ground reflection did not create large areas where the direct signal was seriously and continuously affected. Thus the relatively simple concept of "line-of-sight" (category 0) was retained.

The previous PATHCAT program had provided for two main terrain obstructions in the propagation path, based on measurements made to investigate this aspect ^(2.33, 4.24), and some unpublished research into the incidence of obstacle gain. However, the recent study concentrating upon UHF measurements convincingly demonstrated that at these frequencies provision for a second diffracting edge does virtually nothing to improve the precision of this prediction. It was concluded that the value of edge definition was confined in this type of prediction to the first diffraction, which generally defined the line-of-sight range of a transmitter. Thus provision for a Category 2 profile was dropped from the basic interference prediction.

The means of defining terrain obstructions was improved following an investigation of the nature of diffracting edges. A pattern recognition program was used to group the profile shapes of edges taken from many thousands of samples. As a result of this and the SVF work described earlier, the distance from the receiving antenna for which the simple TCA correction was obtained was increased from 5 (the value used in the original PATHCAT program) to 15 km. As with detailed meteorological information, this is an area where substantial improvement could be achieved if more terrain data is used, in particular to define the horizon range.

The subject of mixed-path propagation was researched extensively, because this is the route whereby the majority of serious levels of interfering signals reach receivers in the UK. Important

factors apart from the overall length, were the distances of the terminating antennas from the sea, and the nature of the overland sections. A method of interpolation proved successful for short-percentage time prediction, whereby the rate of decay of field strength along the path was determined using appropriate overland and oversea curves. Thus where a land/sea intercept was reached, the field strength at that point defined by the overland curve was transferred to the oversea equivalent, and the decay onwards defined by the latter. This approach was unsuitable for periods of time prediction exceeding 10%, but the short-percentage time results were acceptable. Research showed that the mixed path calculation was an aspect of the method that could profit substantially by using more meteorological data, but as mentioned before, these possibilities were not pursued for the present prediction.

In contrast to the fairly substantial modifications to the field strength/distance curves, there were only a few changes affecting surface ground cover and receiving antenna height gain; much of this information had already been thoroughly researched and there were no new results. Provision for four types of ground cover were included in the revised prediction - rural, suburban, urban and dense urban, and the extent of receiving antenna height gain was assessed on the basis of the average height of structures in such areas. In the original program, arrangements were provided to adjust the prediction for mobile equipment dependent upon the relationship between the orientation of the route followed through the buildings and that of the propagation path, but this ambitious and somewhat suspect adjustment was dropped from the revised prediction.

One further factor mentioned here concerns the correlation in time and space between incoming unwanted signals, because this affects the overall perception of multiple interference, and its subsequent calculation. To what extent do individual signals add to increase the instantaneous amplitude, or, by occurring sequentially, extend the duration of the interference? The outcome is obviously affected by the modulation system used for the transmission, and early investigations using two or three interfering sources suggested that with analogue transmission, the coherence of the interference pattern visible on a television picture begins to break down and tends towards white noise, requiring a change in the protection ratio. But the situation with digital modulation is

more complex. In researching the propagation aspects of multiple interference, the measurements not surprisingly revealed that signals arriving from approximately the same direction, traversing similar propagation paths, were likely to be positively correlated in location. Correlation in time depended on the extent of stable upper air conditions. If abnormal propagation is simultaneous on the several paths arriving at a single receiving point from interfering transmitters, then combining the individual signals by some form of amplitude addition is appropriate. Where there is no positive correlation in time, then probability multiplication is applicable. In its present form, the program is based upon the single national airstream, and assessments of multiple interference are based on that simplified concept. Ideally, having produced field strength predictions for each source, the program should go on to predict a graph of the multiple interference level as a function of time duration, but again this needs detailed meteorological statistics.

METHOD	SAMPLE SIZE	SOURCE AND %T	PREDNMEAST (dB)	STAND. DEVL (dB)	PATH LENGTHS (km)
Rec.370	354	UK (All)	-1.9	10.7	50 - 950
PATHCAT	345	UK (All)	3.6	10.4	50 - 950
Rec.370	116	UK (1%)	-4.3	12.2	200-550
PATHCAT	116	UK (1%)	-2.8	11.1	200-550
PATHCAT 2	116	UK (1%)	0.7	9.4	200-550
Rec.370	92	UK (1%)	-9.6	11.4	50-200
PATHCAT	92	UK (1%)	-6	11	50-200
PATHCAT 2	92	UK (1%)	-1.6	9.7	50-200

TABLE 32
COMPARISONS OF UHF PREDICTIONS
WITH MEASUREMENTS

"PATHCAT 2" refers to the second version of the program

As mentioned before, it was impracticable to report fully on the accuracy of the improved PATHCAT prediction because by modifying many of the reference measurements, results using other techniques are unfavourably presented. However, Table 32 gives some figures. This reproduces two entries from Table 18 of Chapter 3, showing comparisons between the original program and the Recommendation 370 predictions. The figures are from overland and oversea paths, and include the principal percentage time results taken from the experiments, i.e., 1%, 10% and 50%. The final six entries in Table 32 show the results of using the present and revised predictions to give 1% time predictions, sub-divided to show distances up to and beyond 200 km.

As expected, the Recommendation predictions are poor when compared with the revised measurements, whereas the PATHCAT 2 results not surprisingly are more favourable, the method having been based on the new evidence. The most notable impact is upon the results for 1% time, particularly for the middle distances, i.e., from 50 to 200 km, where Recommendation 370 substantially underestimates the 1% time field strength available at 50% of the receiving locations. Comparing the original PATHCAT method against the revised measurements also produces underestimates, but again as expected, these improve in the second version. The differences are particularly striking on oversea paths, revealing the fact that the UK is particularly susceptible to interference from foreign stations because of the greater likelihood of stable propagation conditions.

Before closing this chapter it is appropriate to return briefly to one other feature mentioned briefly in Section 4.3.2. The bulk of the measurements used as evidence were taken from a period of 32 years, but these were also compared with some even earlier results. For example, VHF measurements made in the Thirties extending up to paths well beyond the optical horizon were repeated 50 years later, and correlation with the daily windflow and pressure data suggests that there is an increase in field strength over this period. Not many results have been examined so far, but the evidence is convincing, and raises interesting questions. Assuming the validity of the measurements (and there is no reason to doubt this), propagation conditions seem to have improved, for whatever reason.

Overall, it is concluded that a more incisive and objective analysis of the field strength measurements, combined with an assessment of meteorological statistics, has resulted in an improved means of predicting the theoretical extent of a point-to-area service, i.e., the ratio between the wanted and unwanted signals. There is potential for further substantial improvement. In the next chapter, this new prediction in its present form has been used as the basis for comparison with detailed engineering reports of reception, and with records of subjective responses from the public.

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ANNEX 1
LONG-DISTANCE RECEPTION TESTS – PRINCIPAL EXPERIMENTS

TRANSMITTER	RECEIVERS	FREQUENCY (MHz)	DISTANCE (km)	PATH TYPE Land, Sea, Mixed	DURATION
Scheveningen	East Coast*	94.35	198 - 950	S	07.54 - 09.55
Scheveningen	East Coast*	187	198 - 950	S	04.57 - 12.58
Crystal Palace	Caversham	41.5	62	L	06.61 - 12.62
Sutton Coldfield	Caversham	58.25 and 88.3	138	L	06.61 - 12.62
Wenvoe	Caversham	63.25 and 88.95	161	L	06.61 - 12.62
Peterborough	Caversham	63.27 and 90.1	121	L	06.61 - 12.62
North Hessary Tor	Mursley	48.23 and 88.1	274	L	06.61 - 12.62
Crystal Palace	Mursley	41.5	77	L	06.61 - 12.62
Sutton Coldfield	Mursley	58.25 and 88.3	101	L	06.61 - 12.62
Wenvoe	Mursley	63.25 and 89.95	180	L	06.61 - 12.62
Wrotham	Caversham	89.1	88	L	06.61 - 12.62
Rowridge	Mursley	88.5	146	L	06.61 - 12.62
Pontop Pike	Ottringham	180.4 and 560	172	L	01.57 - 06.58
Pontop Pike	Dorset Head	180.4 and 560	214	L	01.57 - 06.58
Pontop Pike	Mursley	180.4 and 560	338	L	01.57 - 06.58
Pontop Pike	Kingswood	180.4 and 560	420	L	01.57 - 06.58
Pontop Pike	Beddingham	180.4 and 560	473	L	01.57 - 06.58
Sutton Coldfield	Mursley	180.4 and 495	100	L	07.54 - 11.56
Sutton Coldfield	Kingswood	180.4 and 495	183	L	07.54 - 11.56
Sutton Coldfield	Beddingham	180.4 and 495	237	L	07.54 - 11.56
Holme Moss	Mursley	560	190	L	07.55 - 11.56
Holme Moss	Kingswood	560	272	L	07.55 - 11.56
Holme Moss	Beddingham	560	326	L	07.55 - 11.56
Scheveningen	Happisburgh	560	198	S	03.63 - 06.64
Scheveningen	Tacolneston	560	217	M	03.63 - 06.64
Scheveningen	Feltwell	560	258	M	03.63 - 06.64
Scheveningen	Peterborough	560	316	M	03.63 - 06.64
Scheveningen	Skeffington	560	356	M	03.63 - 06.64
Scheveningen	Bawdsey	774	196	S	04.65 - 07.67
Scheveningen	Manningtree	774	218	M	04.65 - 07.67
Scheveningen	Brookmans Park	774	307	M	06.66 - 07.67
Scheveningen	Hatfield	774	311	M	08.65 - 09.66
Scheveningen	Kingswood	774	321	M	04.65 - 07.66
Scheveningen	Caversham	774	365	M	04.65 - 09.65
Scheveningen	East Coast*	560	198 - 950	S	06.59 - 06.61
Scheveningen	East Coast*	560 and 774	198 - 950	S	10.61 - 12.63
Pontop Pike	Dishforth	774	85	L	06.59 - 06.60
Pontop Pike	Moorside Edge	774	140	L	01.59 - 06.60
Pontop Pike	Dorset Head	774	214	L	01.59 - 06.60
Pontop Pike	Mursley	774	336	L	01.59 - 06.60
Pontop Pike	Kingswood	774	420	L	01.59 - 06.60
Pontop Pike	Beddingham	774	473	L	01.59 - 06.60
Rowridge	Alderney	501	121	S	02.67 - 02.69
Rowridge	Torteval	501	167	S	02.67 - 09.70
Caradon Hill	Torteval	533	174	M	07.69 - 07.71
Stockland Hill	Alderney	756	137	M	08.70 - 11.70
Portland	Alderney	666	95	S	02.70 - 11.70
Rowridge	Digosville	471 - 557	110	S	03.76 - 09.76
Le Havre	Christchurch	653	193	S	07.68 - 06.70
Le Havre	Kingswood	653	201	M	07.68 - 06.70
Belowda	Widley	876	275	L	08.58 - 07.60
Belowda	West Beckham	876	500	L	01.59 - 03.60

*Receiving sites for the East Coast experiments were sited at Happisburgh (198 km),
Flamborough Head (365 km), Newton (543 km), Aberdeen (690 km), and
Lerwick (950 km).

ANNEX 2
LONG-DISTANCE RECEPTION TESTS – UHF EXPERIMENTS

TRANSMITTERS	RECEIVERS	FREQUENCY (MHz)	DISTANCE (km)	PATH TYPE Land, Sea, Mixed	DURATION
Cuxhaven	Whitburn	495	660	S	04.62 – 12.64
Cuxhaven	Slough	503	672	M	03.61 – 09.61
Caen	Christchurch	510	212	M	07.68 – 06.70
Caen	Kingswood	510	259	M	07.68 – 06.70
Caen	Mursley	510	332	M	07.68 – 06.70
Caen	Caversham	510	281	M	07.68 – 06.70
Dusseldorf	Wickhambrook	535	468	M	11.61 – 12.64
Dusseldorf	Banbury	535	599	M	05.62 – 12.64
Dusseldorf	Aldeburgh	535	396	M	11.61 – 07.64
Dortmund	Aldeburgh	535	408	M	10.60 – 10.61
Dortmund	Wickhambrook	535	480	M	06.61 – 10.61
Dortmund	Slough	535	554	M	03.61 – 09.61
Scheveningen	Pontop Pike	560	505	M	05.60 – 06.61
Crystal Palace	Bawdsey	573	120	L	03.65 – 07.67
Crystal Palace	Caversham	573	61	L	03.65 – 07.67
Crystal Palace	Manningtree	573	98	L	03.65 – 07.67
Crystal Palace	Peterborough	573	122	L	03.65 – 07.67
Crystal Palace	Mursley	573	78	L	03.65 – 07.67
Crystal Palace	Tacolneston	573	147	L	03.65 – 07.67
Crystal Palace	Sunrising Hill	573	125	L	06.64 – 12.65
Crystal Palace	East Harptree	573	180	L	10.64 – 12.64
Crystal Palace	Bearley	573	145	L	06.64 – 12.64
Crystal Palace	Aldeburgh	573	141	L	10.64 – 12.65
Crystal Palace	Banbury	573	111	L	06.64 – 10.65
Crystal Palace	Shrivenham	573	111	L	01.65 – 12.65
Crystal Palace	Stow-on-the-Wold	573	127	L	01.65 – 12.65
Crystal Palace	Peatling Magna	573	141	L	06.65 – 04.66
Crystal Palace	Halwell	573	283	L	06.65 – 09.66
Crystal Palace	Great Baddow	581	51	L	03.63 – 07.63
Lopik	Wickhambrook	625	308	M	08.61 – 02.62
Lopik	Aldeburgh	65	237	S	09.60 – 07.62
Sutton Coldfield	Brookmans Park	629	149	L	09.66 – 09.67
Sutton Coldfield	Hatfield	629	144	L	09.66 – 09.67
Crystal Palace	Darlington	650	356	L	02.58 – 08.58
Crystal Palace	Castleton	650	208	L	03.58 – 08.58
Le Havre	Caversham	653	234	M	07.68 – 06.70
Le Havre	Mursley	653	282	M	07.68 – 07.70
Pontrop Pike	Slough	774	384	L	01.59 – 06.60
Huisduinen	West Beckham	950	222	S	11.58 – 03.60

5. A Review of Coverage Estimates

5.1. Summary

This chapter reviews past methods of coverage estimation and presents a new prediction for the existing terrestrial analogue television network. This has used the modified techniques that have been described in this thesis, and other information which will be described. It is believed the outcome is a realistic appraisal of the situation which existed in the late Eighties when the service probably achieved its peak audience. Evidence such as this could allow the process of duplication to be monitored, and it would also permit the examination of the planning methods which are being used for the re-engineering process. Currently, however, it seems likely that the project will proceed without further fundamental research, dealing with any negative public reaction if and when it occurs. In any case the move to digital is accompanied by all sorts of commercial activities that will influence public choice, and future strategy is opaque. There is also a steady migration away from terrestrial services to those provided by the satellite and cable options, so the extent of digital duplication which must be achieved by the terrestrial network is very uncertain. Nevertheless these dynamic national and international developments will surely demand that the ongoing situation is monitored.

Although concentrating upon the television services, the chapter starts by briefly summarizing the developments that have taken place in the radio networks, to complete the earlier references. The complications of coverage assessment in the past are then described in more detail, in order to understand how the present situation has evolved. The revised PATHCAT program has been used to compute the service areas of several UHF transmitters, and these quantitative results have been compared with the earlier coverage estimates. As a final check on the situation, the estimates have

been correlated against public reports on the technical quality of their service. Some observations are also presented concerning the planning of the digital network, concentrating on the impact upon coverage of the features examined during this project.

5.2. General Observations on Radio Broadcasting Coverage

In common with the television services, the coverages of most national and some local radio broadcasting transmitters have been quantified in the past using field strength measurements, the required levels having been specified following listening tests to define the quality of reception. The fundamental difference between radio and television coverage is that the former has been assessed on an area basis, it being assumed that listening could also take place in a moving vehicle. Therefore, adequate service had to be provided in open country, and not just to the antennas installed at fixed locations. The "mobility" of radio reception and its ability to provide background ("wallpaper") entertainment demanding no great concentration from the listener are often cited as advantages, and certainly the closing years of the Twentieth century witnessed a substantial resurgence in radio usage.

Coverage planning of the VHF/FM radio transmission services received less attention than those of the television networks, although much research was carried out in the early years on development. One early reason for this was the reluctance within the BBC to give them the necessary priority, preferring instead to concentrate upon the LF/MF outlets, due to uncertainty regarding audience requirements and market trends. The FM transmissions were seen as high-quality sources, which could only be enjoyed in the quiet ambience of the home. They needed relatively expensive high-quality receivers, fixed directional receiving antennas and the use of horizontal polarization to cut down interference, especially that generated by inadequately-suppressed vehicles. The introduction of stereophony and "hi-fi" produced much publicity concerning the placing of speakers and the reproduction of the full-frequency range. Attempts to receive this high-quality service by a minority mobile audience were

regarded by many senior broadcasters as little more than ambitious experiments which would fail to reproduce the full quality of the expensive service.

However, mobile reception received something of a boost in the UK through the AM channels when radio services expanded in the Sixties and Seventies, brought about by the introduction of many new stations radiating popular material, often including local information. The newcomers enjoyed immediate success because some of them "pirated" frequencies relatively free of interference. Most listening was done during daylight hours, so the high interference levels that occurred on the LF/MF bands after dark were almost irrelevant. Similarly, interference was not a dominant feature in the coverage of the new low-powered local radio stations, which had limited ranges. Those concerned with the development of the VHF/FM high-quality output attempted to exploit this new market, and in particular very considerable efforts were made by German receiver manufacturers. In Germany, of course, development of the VHF band for radio was inevitable following the '39/45 war, whilst UK industry had continued to concentrate upon the modestly priced but commercially secure AM technologies.

The VHF market did eventually expand, including the potentially profitable car sector. The transmission services were improved to meet this demand, partly by enlarging the transmitter network, and partly by introducing new polarization modes, such as vertical and slant, bringing benefits to mobile reception. These improvements, however, were not completely realised on the national networks, mainly because most of the VHF sound transmitters had been installed at television sites, and some of these were not ideal for achieving the area coverage required for the radio network. It was noted at an early stage that the first motorways built in the UK seemed to pick a careful path between the service areas of the television transmitters – a natural outcome because the latter were designed to serve the urban areas carefully bypassed by the new roads. Thus many of the mobile users drove through fringe areas of the VHF transmissions, and stayed with their old AM services.

There has always been much discussion concerning the standards required for VHF/FM reception, taking account of the types of listening environment. Audiences were broadly divided into dedicated and casual listeners, either in the home or in the car, but different types of programme content demand appropriate listening conditions. For example, compare the fairly limited dynamic range of a news reader with that of a symphony orchestra. The frequency-sensitive and constantly varying levels of background noise in a car do not provide the ideal listening environment for the latter. Many reports issued over the years by BBC Audience Research repeatedly comment upon the unique problems of mobile reception. In this respect the application by the broadcasters of techniques to compress the dynamic range of the transmission always has been a continuing source of heated argument amongst the cognoscenti. However, field strength standards for each type of service were prescribed, and estimates of coverage produced.

Unfortunately, measurements had to be limited, and many of the estimates for the BBC stations were obtained using the results of VHF Band I surveys. Comparison of Band II measurements against those in the adjacent VHF bands uncovered some curious propagation discontinuities. There was substantially greater spatial variation in Band II, and many experiments were carried out to investigate the choice of polarization, a feature which also influenced diffraction losses and multipath. Assumptions made at the time of the Band II developments attempted to incorporate a mass of detail, some conflicting, but subsequent reports of coverage cast doubts upon some of the predicted service areas.

The introduction of cassette and compact disc recorders led to further audience reaction. Freed from the very obvious problems of the "weakest link", these gave higher quality, and radio audiences declined, apart from those listeners interested in speech (news, talks, information announcements, etc.), and pop music, which often demanded very limited dynamic range anyway. The national broadcasters in particular struggled to deal with an ongoing dichotomy between professional standards and audience size, difficult for those attempting to satisfy increasingly opaque public service objectives.

In 1981 a report was published by the BBC which recommended that the future of radio should rely on an expansion of the VHF services ^(5.1), observing that the interference levels on the LF/MF services would continue to deteriorate. However, commercial competition for services using these popular frequencies continued, and the BBC decided to maintain its operations in these bands. As a result the VHF services still did not receive the attention needed to achieve the specified objectives. In 1985, following extensive work throughout Europe the author produced a report which dealt in depth with the subject. This was never published, due to the controversial nature of some of its material which discussed the reasons for the non-popularity of VHF radio in the UK, including the wasteful duplication of programme material across the spectrum. A presentation in the following year based on this research was also critically received, although again it was a factual analysis of the situation and presented several constructive suggestions. In particular it repeated the proposal that duplication should be abandoned in favour of the earlier recommendation of concentration upon VHF delivery ^(5.2). Within public service broadcasting this was regarded as risky, because audiences might be lost.

The closing years of the century were to see a substantial amount of work on certain aspects of the radio services, with additional transmitters and several new stations. However, knowledge of the exact public coverage of the core national networks did not advance a great deal. It is certain that public demand has revived - this was noted in a survey by the Joint Industry Committee for Radio Audience Research in 1986, concentrating upon independent local radio stations, advertisers and agencies, which reported the previous decline in listening had been reversed ^(5.3). Within the service areas of these stations, 793 million hours were spent listening to the radio each week by 35.4 million adults, an increase of 24% since 1984 against an increase in population served of only 8%. Although compiled on a different basis, BBC figures were similarly encouraging.

Radio broadcasts are now transmitted on satellite channels alongside television services, and digital radio has been introduced. The information technology that has accompanied the mobile telephone

phenomenon has also affected the radio scene, many developments are taking place, and more can be foreseen. It would be difficult if not impossible to analyse the overall coverage situation, not only because of the multiplicity of stations, but also in recent years the number of audience research sources has escalated, and there have been quite drastic changes in the individual methods of determination. For these reasons, and more importantly because it is not the prime interest in this thesis, the subject of the true analysis of terrestrial radio coverage is not pursued here.

5.3. Terrestrial Television Coverage Assessment

5.3.1. The Evolution of Methods

In the early days of the television service the coverage of each station was defined by the field strength contour which satisfied the minimum grade of service. As described in Chapter 1, in the case of the early Band I stations this was set at 40 dB μ V/m, and the number of people served was estimated on the basis of a population count within that limit. Most of the early, single-contour coverage maps provided little in the way of detail. The minimum field strength was very low, the effect of terrain at 45 MHz was relatively small, and the coverage seemed extensive. Sometimes quite large areas of poor reception within the nominal service area were not shown, but these were early days, and there were few technical criticisms from the public, generally overawed by the new technology.

Following the London (Alexandra Palace) station, the opening of a second transmitter at Sutton Coldfield to serve the Birmingham area introduced a new factor. There was an overlap area to the north west of London in which reception could be obtained from both stations, and some viewers were confronted with the question of choice. If professional receiver installers were used, then they usually made the decision, and they gradually acquired the local knowledge needed. This was generally determined by signal strength, although sometimes influenced by the viewer's decision when alternative regional programmes became available. Later, co-channel interference became a factor, and often replaced noise levels in the specification of service limits. Even in the early days the effects of

RF interference were illustrated by the occasional appearance of transmissions from the USA received via sporadic E, which affected the Channel 1 transmissions from Alexandra Palace more than those from the Channel 4 station serving the Birmingham area. However, it was to be some years before the concept of "preferred service" population counts emerged, which were to give more realistic figures for the individual performance of each station. Thus estimates for the early VHF Band I development showed two types of result, the first reporting the gross population within the minimum field strength contour of each station, and the second giving a national total for the whole network, in which the people in overlap areas were counted only once. Although simple for the relatively widely-spaced VHF networks, the situation became much more complicated when the UHF stations opened, and Table 33 hints at the problems which began to emerge. The stations are listed in the order of opening,

Station (Area)	Gross Population	Net Population	Cumulative Net (% UK)
Crystal Palace (London)	11171226	11171226	20.98
Sutton Coldfield (Midlands)	5410753	5410753	31.14
Wenvoe (South Wales)	841336	841336	32.72
Hertford (London relay)	35820	26055	32.77
Tunbridge Wells (London relay)	103600	79844	32.92
Winter Hill (Lancashire)	6333618	6254012	44.66
Emley Moor (Yorkshire)	3901886	3798060	51.79
Rowridge (Isle of Wight)	1761818	1757652	55.09
Black Hill (Scotland)	2881966	2881966	60.5
Reigate (London relay)	215688	21325	60.54

TABLE 33
FORECAST COVERAGE OF UHF SERVICE

The "gross population" is the number of viewers within range of the station. The "net population" are those viewers uniquely served by the new station at the time of its opening. The "cumulative net" is the proportion of the total population served at that stage.

thus the first three main transmitters, their UHF service areas all geographically isolated, produce identical gross and net population figures, and the cumulative UK net figure is simply produced by adding these. The fourth and fifth are relays in the London area, and their service areas overlap that already provided by the parent at Crystal Palace, so their net figures are less than their gross results. An apparently unsatisfactory example is provided by the Crystal Palace relay at Reigate, where the

station provides a new service to less than 10% of its gross coverage, the remainder duplicating areas already served by the main station. This situation became commonplace as the network grew, and although superficially inefficient, duplication of this nature offered choice in the later stages when the channels became congested. The appearance of regional and national programmes further complicated coverage assessment, e.g., service provided to an area of Wales by an English transmitter might well be regarded as unacceptable.

The early VHF estimates were produced using all sorts of evidence, ranging from official census returns to detailed figures taken from local records, Automobile Association and Royal Automobile Club publications. The process was crude until computer techniques were introduced to deal with the UHF development in the Sixties. Briefly mentioned in Chapter 2, the terrain database in which representative heights were stored for each 0.5 km square of the UK was extended to include ground cover and population estimates. Both of these items were deduced from a visual inspection of 1:25,000 scale maps, combined with the census population counts. Many assumptions were made, primarily because the maps seldom distinguished between factories, offices and inhabited buildings. However, an acceptable basis was devised, and although the precise figures misleadingly suggested great accuracy, it was at least consistent.

The population database was used to provide routine service area counts, and was also extensively applied to various research projects. Some were remarkably ambitious. One example in 1971 estimated the number of households in the UK where terrestrial reception was likely to be affected by building shadows. Later this same experiment was extended to report the results for satellite reception. Another project reported the relationship between population density and the penetration of wired systems. In the borough of Pimlico, for example, where the population density at that time approached the maximum for the London area (80 households per hectare, about 6,000 people in each 0.5 km square), many hypothetical receiving antennas mounted at the standard height of 10 m. a.g.l. would have been in building shadow and therefore unserved. Factually, a detailed on-site study conducted at

the time revealed that only five households in the area were without a service, because 70% of the population were using cable systems and most of the remainder relied upon wired distribution within blocks of apartments with roof-mounted antennas well above 10 m. Early results such as these underlined the fact that coverage analysis and efficient service planning involved much more than simply providing a specific field strength to an ideal receiving antenna at a height of 10 m. a.g.l., although, as mentioned earlier, the availability of alternative sources was officially ignored in the planning of the national networks.

Certainly the use of field strength alone to define coverage was questioned when wideband transmissions were introduced. Multipath interference was an early concern, especially obvious in the early stages of the UHF plan when "chains" of relay stations began to appear. The existence of a persistent "ghost" on the reception of the parent station at a relay relying on a direct off-air feed would demand an alternative reception site or, in the extreme case, an expensive Post Office link. But with this exception, which required action by the broadcaster at the transmitting end, the planning processes remained remarkably insulated from public reaction for some years. In retrospect, this is surprising, because the engineers of the Post Office had taken a leading part in the original specification of picture quality ^(5.4), and their colleagues were daily involved in the analysis of interference as the network developed ^(5.5, 5.6, 5.7, 5.8). There was further information on the subject through the receiver industry and their association, BREMA ^(5.9), who were aware through the network of dealers of the viewers' experiences of the developing service. Feedback also came directly through the technical public relations' departments of the broadcasting organizations, in the case of the BBC this was their Engineering Information Department (EID). Unfortunately with the exception of the latter, all this information was scattered, and there was no attempt to build up constructive feedback channels. However, the onset of co-channel interference changed the situation quite radically.

5.3.2. The Impact of Co-Channel Interference

The interference caused to VHF television reception caused by abnormal propagation via the ionosphere was regarded as a phenomenon when it first appeared. However, it heralded the advent of the far more serious challenge of co-channel interference transmitted over relatively short distances through the troposphere. It was to be this factor that would dictate the minimum field strengths and hence the service area limits, rather than the noise levels of the receiving installations.

Many of the early difficulties had to be resolved by practical tests, because prediction could not provide the detailed answers needed. Just one example is mentioned here which gives some idea of the many tedious experiments which ensued. In order to protect French services across the English Channel against interference from a very low power VHF television relay in Folkestone, measurements extending over some months had to be completed before permission was granted by the French administration for the BBC station, provided its power towards France did not exceed 1.5 watts. This called for a highly expensive solution, because a complex transmitting antenna had to be designed for this tiny station. This was the first of many, most of which affected far larger transmitting installations, and the problems escalated as planning moved into the dense networks required for UHF coverage.

The means of communicating the service planning requirements to the transmitter designers was through a templet. In terms of radiated power, this showed the minimum requirements needed to achieve the planned coverage, and the maximum limits which must not be exceeded to protect the service areas of other stations sharing the same channel. The minimum requirements were usually decided following a site test, or occasionally employed predictions. The maximum restrictions were generally based upon predictions, although in very difficult cases measurements had to be made. Protracted discussion between transmitter/antenna designers and planners would often follow, and as the networks developed the specifications became increasingly complex. Solutions were expensive, and awareness of the frailty of some of their planning tools complicated the decisions for the planners.

The practical constructors would point out that it would cost thousands of pounds to satisfy a particularly demanding horizontal radiation pattern (HRP), and accuracies of a fraction of a decibel became significant. Furthermore, the difficulties were not confined to the horizontal plane. The vertical radiation pattern (VRP) was often critical and even more frequency sensitive, especially across the wide frequency range of four programmes transmitted from each UHF station. Complaints from the customers at the distant edges of the service area were to be expected; it was much more difficult to explain problems to those within a kilometre of the transmitting mast. Then additionally problems with other spectrum users, such as radio astronomers, military operators and civilian emergency services, had to be considered. Often these required the fundamental, intermodulation, and many harmonic frequencies radiated by broadcast transmitters to be kept to a minimum in order to protect the transmission and reception channels of these operators.

The angles subtended at the antenna of a new station to protect an existing or planned service depended upon the extent of the latter, and so attention had to be focused upon the precise limits of each. The concept of "preferred service areas" was introduced in the Sixties, whereby under pressure to produce plans for relay stations to fill in relatively small deficiencies in the service, lower priority was given to protecting existing reception in an area believed to be served by more than one transmitter. Much information was needed to produce such a map. Initially based upon measurements and predictions within the planners' archives, this eventually included information from others, notably contacts with reliable local dealers who had first-hand knowledge of local conditions

Whilst it was comparatively easy to prepare these maps for the VHF service, which had been in operation for some time and had been extensively surveyed, it was very difficult to build up the UHF equivalent. This was a vital requirement, because the network was likely to require at least a thousand stations, and the construction programme was going to extend over many years. The efficiency of the ongoing planning would be affected constantly by forecasts of the eventual geographical distribution of the transmitters, the interference calculations, and the approximate service areas. Even if the technical

work of prediction alone was considered, then it was impossible to forecast the state of the network more than a few years ahead. Constantly more was learned about the differences between planned and actual coverage, for example the density of the network meant that in some favoured areas viewers could choose from two, three or even four sources, often well outside the theoretical range of the selected transmitter. Ignorance of these within planning departments meant that these reception pockets might well be affected by plans for new stations, so interference calculations became increasingly complicated. The dynamic state of the transmitter construction programme, the ongoing discussions between broadcasters, public representatives, land owners, commercial interests, local councils and government departments, all these were factors which confused attempts to produce a reliable forecast of the unfolding plan.

Frequency Band	Limit (dBU)	Environment	S.D. Locn. (dB)	% Served
Band I	40	Rural	5	91.5
do.	40	Urban	5	44.3
do.	40	80%/20%	5	53.7
do.	47	80%/20%	5	78
Band III	40	Rural	8	89.1
do.	40	Urban	8	44.9
do.	40	80%/20%	8	53.7
Bands IV/V	70	All types	10	85.5

TABLE 34
FORECASTS OF POPULATION SERVED
INSIDE LIMITING CONTOURS

The field strength limit in this table assumes this is the median value, and the "percentage served" is calculated further assuming a log-normal location distribution having a standard deviation as shown.

Nevertheless, an early study ^(1.78), suggested that the preliminary standards adopted for the UHF service could provide a better result than that achieved at VHF, *if the spectrum offered enough space*, and Table 34 lists some of the important results of the work. This analysis was based upon picture quality assessments, field strength/distance curves, and graphs available at the time which quantified the local variation of field strength. The limiting field strength contour was defined initially as the minimum value required in rural and urban areas. The 1952 Stockholm Conference had set the absolute

minimum for Band I at 40 dB μ V/m, although by 1955 figures of 54 dB μ V/m in urban residential areas and 74 dB μ V/m in industrial zones were being used in planning work on Band I because of the higher incidence of man-made noise in towns ^(5.10). The percentage of the population contained within the limiting contour was calculated for three environments – rural, urban, and an 80%/20% mix, the latter based on the fact that 80% of the population of the UK lived in towns containing more than 5,000 people.

The early forecast described above provided some encouraging results for the UHF supporters, but it also underlined the dependence of the results upon the contributing factors, particularly the picture quality assessment curves. It became clear as the plan developed that contrary to previous assumptions, whereby a single curve defined audience reaction to both picture quality and noise impairment, co-channel interference caused quite different subjective reactions. There had been some concern that the original tests had been too stringent, and that protection ratios were too high. The assessors were “expert”, viewing distances during the tests were much shorter than those used by viewers, and in any case the latter were less critical. But as mentioned earlier, the spasmodic nature of co-channel interference and its relatively coarse patterning was unlike the “boiling porridge” of noise, and was readily perceptible at all viewing distances. The extent of annoyance also depended upon factors not previously considered, such as the duration of the problem, the nature of the moving patterns, and the viewer’s interest in the programme material.

There are many references to work on the visual impact of RF interference upon a television picture, and two quoted here deal simply with the basic optical effects and the impact of a single interfering source upon reception as they were assessed at the time ^(5.11, 5.12). It is an intensely complicated subject, and probably because of this the basic planning parameters defining the international protection ratios required to diminish the effects of interference which were set up 40 years ago remained unchanged. There has been some work on the mathematical aspects of multiple interference, as previously mentioned, and the results have been variously applied in the interference calculations, but these results

have never been compared on any significant scale with the viewers' reactions. The value of a single figure representing the multiple interference level has been to relate the significance of individual contributions.

Thus the forecasts of coverage which were produced during the construction stages of the UHF plan in the UK remained firmly based on the early planning parameters. The coverage estimates which emerged during that time are briefly reviewed below.

5.3.3. Ongoing Coverage Assessments

As the UHF construction programme proceeded, the growing complexity of the interference problems was revealed by the computer output presenting the service planning calculations. Based upon the current version of the BBC prediction program, these listed the levels of interference from co-channelled stations at a number of test locations, selected around the periphery of each existing and planned service area. Limited calculations to reveal the details of single stations passing through the planning phase were made almost daily, but at intervals a full analysis was conducted, in which results for all the stations currently included in the network were produced. Table 35 shows the main statistics for five such analyses, carried out during the period 1964 – 1996. Not included in the Table but also considered as part of this evidence, because they provided an international comparison, have been the results from the important European Offset Conference of 1968^(5.13), although these used only the Recommendation 370 prediction. Not surprisingly they produced very high figures. The numbers of stations were those included in each analysis, and whilst the UK total gradually increased as the network grew, the number of foreign transmitters – included in the total – remained fairly constant. This is because most of the interference caused by the latter came from the high-power installations included from the start of the plan, the program rejected “insignificant” contributions from the much greater number of foreign relays.

Year	Number of Stations		Test Locations	% Unserved
	UK	Total	(UK only)	(5% Time)
1964	116	422	530	3
1969	298	617	1740	7
1972	422	771	2220	14
1984	845	1207	5290	23 (3)
1996	1014	1530	13200	41 (11)

TABLE 35
COMPUTED RESULTS FROM UHF COVERAGE
PREDICTION PROGRAM

The "percentage unserved" is the proportion of the test locations where the predicted level of interference exceeded the minimum field strength standard. From 1984 the wanted signal was also predicted, and these results are shown in parentheses

Over the years there was a very substantial increase in the number of test locations selected for analysis, created by the growing number of relays, ultimately reaching an average of about 15 to 20 for each high-power station, and approximately 10 for each relay. The majority of these small installations had low transmitting antennas, and although they each covered relatively small areas, the need to investigate the influence of terrain upon the field strength predictions in some detail was important. In many cases the siting of a small station was influenced by the direction of other transmitters likely to cause or experience interference, and the information needed to interpret each situation called for a high density of test locations.

The "percentage unserved" result shown in Table 35 was obtained by comparing the multiple interference level predicted for each test location with the specified minimum field strength standard — the actual field strength available from the wanted station was not calculated before 1984. From that time the computer output also included a prediction of the wanted signal, and the percentages of the results where this value was less than the interference level are shown in parentheses in the final column of the Table. The later calculations also gave results for 1%, 5% and 10% time, but for the purposes of routine planning at the time, the 5% level was adopted as the network standard.

With the type of information reported above and other supporting data there were many attempts by broadcasters to obtain additional spectrum space. These reached a peak in the Seventies, when attention was focused on the possibilities of closing down the VHF networks, it being assumed that their services would eventually be duplicated by the UHF systems. This was the stage at which the planners for the first time were able to carry out some co-ordinated research into public reaction to the technical quality of the transmissions. Field trials were conducted in parts of the country where it was considered the problems of duplication would be particularly severe, i.e., where the VHF service was known to be good but where the UHF replacements, threatened by co-channel interference because their spectrum was limited, might well be inferior.

Two main areas were selected. The first was in the East Midlands, covering the area from Northampton to Newmarket, and from Luton to Peterborough. Topographically this was a flat region well-suited to UHF transmission, but high levels of interference were anticipated. The second choice was more undulating, centred on the Solent area and extending from Bournemouth, through Winchester to Brighton. It was thought that although the UHF service might be disadvantaged by a combination of terrain and foreign interference, the large number of high-power stations planned for the region would provide alternative sources in areas of difficulty. Later, to check results in a densely populated area, additional studies were also carried out in London. A great deal of information was produced by many participants during these field trials, but yet again this was not thoroughly researched at the time. Fortunately, it was correctly concluded that the VHF coverage could be duplicated, and it was forecast the numbers of viewers affected by the eventual closure of these services would be acceptably small.

From the mid-Seventies onwards many notes were produced by the broadcasting authorities and by the various administrative and technical committees which analysed the ongoing progress of the duplication process. The estimates published in these relied heavily on population estimates. Most of the notes were concerned with the escalating costs of the UHF transmitter network (there was

increasing emphasis upon the "cost per head" factor), and with the service planning problems. They were not generally circulated beyond those immediately concerned and many were unreferenced, but the author has retained copies and they have provided useful research material.

In 1973 a note issued by BBC Research Department forecast the costs of the UHF network for near-total population coverage (99.4%) of the UK population ^(5.14). This reported that the first phase of the relay station plan – which contained provision for 360 low-power transmitters serving pockets of population exceeding 1,000 people – would bring the total population coverage to just below 99%. It showed the distribution of the unserved population across the country, and forecast that an additional network of 270 very low-power stations costing a total of about £17M could bring the coverage to about 99.5%, although some of these would be only "marginally served". These stations would be planned to serve pockets of population exceeding 500 people. However, it was emphasized that the estimates of the distribution of those unserved was very approximate, because many areas had yet to be surveyed.

By 1976 a further note from the same source reported that a further 80 areas each containing more than 1,000 people had been revealed by more detailed survey work ^(5.15). These were notionally beyond the range of all the existing and planned stations, including the 360 Phase I stations intended to deal with pockets of this size. Many were relatively large in area, within which the population was widely scattered. These examples presented problems, because transmitters having the power needed to reach these ranges could no longer be accommodated in the plan without causing unacceptable interference to existing services. New proposals were prepared for future extension, which modified some of the proposals for the Phase I stations, and included a Phase II, consisting of 250 to 270 relays serving pockets down to 500 people. The national population target was maintained at 99.4%, although it was accepted that some of these would include viewers in Welsh and Scottish regions whose programme would come from English transmitters. Now, however, a significant proportion of the population was to be regarded as served because although their received field strengths were marginal, i.e., in the range

64 to 70 dB μ V/m and occasionally subject to interference, it was believed they could improve upon their reception by using high-gain receiving antennas, head-amplifiers, etc.

The "self-help" concept was extended to pockets of population down to 250 people, which eventually formed Phase III of the relay station plan. An officially-sponsored self-help system was set up, whereby the broadcasting authorities gave technical advice to small groups of people who wanted to establish their own local distribution system. These ranged from small, conventional relays, through "active deflectors" (which did not use a new frequency for transmission but rather re-radiated the incoming signal using carefully-designed systems), to various types of cable installations.

In the examination of the use of marginal field strengths, the prediction of interference was a significant factor. Wherever possible, interference with reception was only accepted in the planning stages if there was an alternative transmitter source, and in this respect the densely-packed UHF network often provided many alternatives. It was not unusual to find five or six sources in use within a small area, especially in hilly terrain, where local reception conditions varied widely. In a situation in which so many transmissions are likely to be used, the major constraint on frequency selection became the need to avoid various risks of adjacent, image channel and local oscillator interference, likely to be continuous, rather than that caused spasmodically by distant co-channel stations. A further complication during the transition years when VHF and UHF television transmissions continued simultaneously, was the effect upon the latter of harmonics radiated by the former.

The decision to close the VHF service was taken and the networks finally closed in 1985. Having regard to the complexity of the problem, it is remarkable that the process went so well. Earlier changes in the television services which had usually involved just one station at a time had often provoked many complaints. Success in the project which involved the closure of well over 100 stations must be attributed to the joint efforts of the many organizations involved, not forgetting thousands of local dealers, and the fact that the close-down occupied more than a decade. During this phase the public

was given the time to compare the two services, and the attractions of the UHF network proved decisive – the plan was successful. Ample notice of the closure of each VHF station was given, using orthodox methods of publicity, and by installing caption scanners at each transmitter, giving specific local information.

The controlled re-engineering process which took place 20 years ago makes an interesting comparison with that which now confronts the planners in the digital conversion project. Because the UHF network which is to be modified consists of ten times as many stations as the old VHF service and many more programmes, a full analysis of its coverage is far more complicated. The next section examines the situation.

5.4. A New Analysis of the UHF Analogue Coverage

5.4.1. The Need, and the Method

The preceding descriptions have exposed the complications that affect the detailed work of service planning. Coverage estimates have been and remain a particularly important feature, because they present the results, and the evidence for further development. They have a vital impact on the expenditure of resources, and this underlines the importance of reliable information.

The process of digital conversion presents new problems, quite unlike those of the almost clinical replacement of the VHF services. If *complete* records of the existing analogue coverage existed, and that of the new service could be accurately predicted, then the planning work would be less daunting. But neither condition obtains. The course of action adopted within the UK to achieve the digital objective has been to assume the present coverage information provided a reasonable basis, and to proceed using the best methods of planning currently available. However, coverage information is inadequate, and this project has presented evidence to suggest that the planning methods may be flawed in certain areas. There has also been one other important development.

In the space of a few years the practical requirement to *duplicate* the near-national analogue terrestrial service has changed radically. Attracted by additional channels (including most of those already available from their terrestrial transmitters), viewers are transferring to the satellite and cable sources. Attempts to retain terrestrial viewers by increasing the number of their “free-view” channels has met with some success, but the attractions of this “free” service are modest, and the future is obscure. Add to all this a fair amount of public confusion. It is apparent that in attempting to meet its objectives of closing the analogue services and possibly selling off the vacated spectrum, the Government is not essentially interested in the means whereby their target of 95% digital usage is achieved. The outlook for the terrestrial broadcasting network is uncertain, it could well become a costly anathema.

Thus the planning objectives for the digital terrestrial network are confused. Logically, and determined to make the most efficient use of the spectrum, the planners aimed for national coverage. A “tailored” approach was ruled out – the migration to satellite and other services is piecemeal, and apart from regional programme aspirations, local reception arrangements are virtually unknown. So the planners still have all the problems of spectrum sharing, protecting analogue reception, etc., even though the audience is probably diminishing daily. They also have to observe the international situation, and ensure that the national services are protected against foreign developments, and do not cause interference to the latter. When combined with the doubts expressed in this thesis concerning the planning methods, there is good reason to be concerned about the outcome.

In this very uncertain climate, a new analysis of the UK coverage of the UHF analogue television service would help to clarify some of the uncertainties. Even a limited review could test the implications of the suspected shortcomings in the planning methods, and provide a more reliable basis for comparison with the digital replacement. With these objectives, the new analysis carried out in this project passed through two stages. Firstly, the theoretical coverage of a sample of UHF stations was calculated using the revised PATHCAT program, and the results have been compared with the ITU and BBC predictions obtained in 1996. The size of this sample has been restricted by the number of

predictions involved, but it includes frequency assignments to a number of main and relay stations which between them served about 25% of the population. Secondly, the outcome of this theoretical assessment has been compared with reports of the viewers' perception of reception quality, effectively for the first time providing evidence of their reaction to the broadcasters' planning standards.

5.4.2. The Theoretical Result

The arrangement for the distribution of the 44 channels within the UHF spectrum allocated to terrestrial broadcasting in the UK meant that nine regular groups each containing four channels was available. Wherever possible, the 36 channels in these standard groups were assigned to the stations in the network, the remaining eight non-standard channels being used to make up groups in those situations where there were local difficulties, e.g., those caused by interface problems with foreign allocations where the channel grouping was different. In this new analysis, interference levels have been predicted for UK transmitters using six channels, and Table 36 gives the main results. They have been sub-divided to show the predictions for 25 high-power and about 600 low-power (relay) installations, the former having ERP's equal to or in excess of 20 kW. In order to place the size of this sample in context, the overall UHF plan for the UK in 1996 assigned frequencies to 164 high-power

CHANNEL	NUMBERS OF UK STATIONS and of (TEST LOCATIONS)		AVERAGE LEVEL OF CCI - 5% TIME (dB)			
	High Power	Relays	BBC Prediction		PATHCAT	
			High Power	Relays	High Power	Relays
24	4 (51)	68 (625)	73	76	77	81
26	7 (124)	88 (923)	65	74	70	76
39	3 (60)	119 (1226)	73	79	77	82
49	3 (47)	128 (1334)	69	77	75	84
51	4 (82)	103 (1219)	70	79	73	82
62	4 (59)	86 (990)	74	79	80	84

TABLE 36
CHANNEL SELECTION AND INTERFERENCE PREDICTIONS

The sample shown in this table contains about 16% of the frequency allocations to the UK UHF network. The average interference levels for both high power and relay stations have been predicted using the BBC and the PATHCAT 2 methods

and 3,589 relay transmitters, giving average numbers per channel of approximately four and 82 respectively. Predictions were carried out using the BBC and the revised PATHCAT programs, both of which take account of local terrain, and the average results for the notional 5% time are shown. The outcome of using the ITU program (Recommendation 370) is not reported here; for the long-range paths the results of that method are substantially similar to those obtained with the BBC technique.

The service areas of the stations in the Table were represented in the predictions by a total of about 7,000 test locations, very substantially increasing the density used in the original 1996 analysis. A full examination would have required predictions of levels of interference from all other co-channelled transmitters at each of these, but with an average in this sample of more than 100 per channel, the scale of the computation can be appreciated. The number of propagation paths was reduced by limiting the calculations to transmitters making a significant contribution to each test location, so the total predicted in the analysis amounted to about 70,000.

Table 36 only shows a brief summary of what proved to be a very complex analysis. The previous chapter has described the nature of the differences between the two prediction methods, so disparities were expected, but the main observations are listed below.

- The revision of the LDR results and the consequent modifications to the method meant that the PATHCAT program predicted higher interfering fields than those obtained using the BBC method. If the 1% time level is investigated, then the difference is greater still. Conversely, the 10% figures are closer, although the BBC/ITU results are still lower on average. The situation reverses at longer time percentages, with the PATHCAT average well below at 50% time.
- There is substantial variation about the 50% location levels of CCI, depending upon the local environment. This is again much more obvious with the PATHCAT method, which is decisively influenced by the terrain clearance angle.

- The multiple interference calculation also revealed the PATHCAT technique produced higher values, because the assumption of positive correlation in time between interfering signals measured at exposed sites supported the application of power addition, rather than probability multiplication ^(5.16). This result is regarded by the author as a more accurate outcome, because the great majority of measurements repeatedly confirmed that the main sources of interference were likely to be transmitters well within 500 km, and the stable tropospheric conditions needed to support abnormal propagation often extended across such an area, influencing most paths simultaneously.
- Continental high-power transmitters were the sources of the highest predicted levels of interference, sometimes sustained for long periods by settled tropospheric conditions over the sections of their propagation paths across the southern North Sea and the English Channel. This result stresses an important feature of the interference situation in the UK. The concept that as an offshore island the services are relatively immune from problems caused by continental transmitters, given the 5% time planning standard, is false. The occasional abnormal propagation conditions that persist on oversea paths heightens the planning difficulties. Seriously affected were test locations on the Lincolnshire Wolds, throughout East Anglia, the south-facing slopes of the Chilterns, North and South Downs, the Weald, and parts of Hampshire, Dorset and the Devon/Cornwall peninsula. The situation was aggravated at test locations where attenuation of the incoming interference could not be achieved by receiving antenna directivity, or screening by the local terrain. Interference in these expansive areas affected large numbers of viewers, because they were mainly served by high-power UK stations. Relay stations, although often threatened by higher levels of interference, covered only a small proportion of the population (the most recent assessment showed that about 12% of the UK population used these sources).
- As expected, overland paths produced much lower levels of interference, although there were cases where exposed receiving sites were affected for relatively long periods. A particular example was the substantially-populated area of the north slopes of the North Downs, where

interference to the service of viewers using Crystal Palace Channel 26 was predicted (and experienced) from a co-channel station in Yorkshire. The relative exposure of many reception sites used for relaying services was also similarly affected, i.e., the quality of their incoming signal was impaired and the interference subsequently re-transmitted. These problems demanded rapid and often expensive solutions.

To obtain further confirmation of the theoretical impact of interference upon the overall UHF service, measurements and very detailed predictions of the wanted field strength for about 2,000 of the test locations within the service areas of main stations were compared with the interference predictions. Table 37 shows these comparisons, in which the levels of the wanted signals have been compared with the interfering signals predicted to occur for 5% time. Where the former exceeds the latter, coverage is assumed to have been achieved, and the figures in parentheses show the results. As mentioned above, these had been selected in areas likely to experience problems, and a parallel study was carried out into a more detailed survey of the Crystal Palace service area. In contrast to the majority of UHF main stations, where survey measurements were concentrated in areas of low field strengths, the complete coverage of this station had been very extensively measured over a period of years. In this case, the BBC/ITU method produced a lower estimate than the national average, because new deficiencies in the service were revealed, although the Pathcat result was only marginally reduced. One reason for this was that the location variation within these areas, being nearer to the transmitter, was generally less than those nearer the limit of the coverage, and the impact of the terrain correction was reduced.

COVERAGE	SAMPLE SIZE	BBC/ITU PREDICTION	PATHCAT
Main Stations	2000	1946 (96%)	1720 (86%)
Crystal Palace	200	182 (91%)	169 (85%)

TABLE 37
EFFECT OF CO-CHANNEL INTERFERENCE UPON COVERAGE

Interference expected to persist for 5% time has been predicted, with the PATHCAT 2 method producing a more pessimistic estimate of coverage.

5.4.3. Comparison with Reception Reports

The foregoing has presented predictions of the effect which CCI has upon the UHF terrestrial television coverage. Depending upon the method used, it is estimated that somewhere between 5% and 15% of the population may perceive this problem. However, whilst clearly a vital measure for planning purposes, the real impact of interference remains obscure. On the evidence of propagation statistics, it is extremely unlikely that it will occupy a solid block of 18 days in the "average" year, or be composed of about 26,000 minute-long bursts. In order to obtain further data, what can be learned from the viewers' reactions to the quality of their service – when and why do they complain? Many sources have produced what are effectively "consumer reports". The new comparisons made here with the predictions of the theoretical coverage have been obtained from the following.

- (i) Reports from broadcasting organizations – for example these include special field trials which have involved technical and non-technical staff, ongoing public relations' activities, and audience research programmes.
- (ii) Reports from the GPO and its successors – examples include interference complaints, licence investigations, and spectrum usage studies.
- (iii) Reports from BREMA members, primarily concerned with the design and operation of the receiving equipment.
- (iv) Information from dealers, responsible for selling, installing and maintaining the users' equipment.
- (v) Projects conducted in four urban areas by the author, intended to analyse conditions at the receiving end and relate these to planning parameters.
- (vi) Consultancy projects where the author was asked to advise independently on the quality of a service.

To obtain some idea of the numbers of complaints concerning reception quality that have emerged over many years of operation it is useful firstly to consider the unsolicited comments received directly from the public by the GPO engineering branches, and the equivalent engineering departments within the broadcasting organizations that receive and process these comments.

Records reported by the GPO for eight separate years during the period from 1961 to 1978, show that the average number of complaints, comments and queries received annually increased from 115,000 to 240,000 ^(5.17). Of these, the proportion with problems with the "weakest link" i.e., an interference difficulty of some sort arising between the transmitter and receiver, increased throughout the same period from 16% to 28%. Some of these problems were traced to the receiving installation, such as an inefficient antenna, faulty feeder, or receiver mistuning. Others were attributed to interference from local oscillators or harmonic radiation from lower frequencies. By 1978 the proportion positively identified as experiencing CCI during periods of abnormal propagation was confirmed at 20%. Some viewers were advised that they were using the incorrect transmitter; this was a common problem in the later stages of the UHF development when many new relay stations were being added. However, advice to change to an alternative transmitter was cautiously given, because of the uncertain and mercurial state of the interference situation, especially in fringe areas. Complainants were often referred to their local dealers.

In the case of the broadcasting organizations, their engineering departments dealing with public complaints concentrated upon technical problems which could be directly related to their responsibilities. If some external non-broadcasting source was the cause of interference, the complainant would be referred to the GPO. The number of complaints received by these departments was much smaller than that accepted by the GPO, and averaged about 25,000 a year, of which again about 20% were identified as being caused by CCI.

There is no direct information from BREMA regarding the numbers affected by CCI, although they were instrumental in encouraging the growth of specialist receiving antenna installation companies, which went a long way towards improving the quality of the receiving installation. In the early Sixties, when UHF services opened, the quality of advice given by local dealers to new customers often reflected initial inexperience. Even during the course of field trials organized ten years later by the broadcasters and the GPO to study the extent of duplication of VHF by new UHF services, it was reported that less than one in five dealers had provided viewers with an efficient installation. However, scrutiny of the results which were maintained by reliable dealers did reveal valuable information, and confirmed the existence of perceptible CCI at about 25% of the receiving locations. This higher figure was anticipated, because the trials concentrated on difficult areas.

Similar results were obtained by the author, when between 1986 and 1997 he researched measurements relating to the UHF coverage in four urban areas in the UK – Bristol, Tunbridge Wells, Guildford and Chichester. By that time the UHF network was largely completed, and local reception conditions had stabilised, i.e., viewers had found the best transmission source. After examining all the technical detail, the nature of the receiving installations in the areas were recorded and assessments were made of reception quality by distributing questionnaires to viewers. About 1,200 were fully completed, and about 25% of these reported periods of CCI. Some were subsequently interviewed by the author – a process which confirmed a long-held observation that most viewers accepted lower standards than those originally agreed during the quality tests many years earlier. However, this remark does not apply to CCI; there was substantial agreement over the annoying nature of this feature.

Nevertheless, whilst it was obvious that the apparent severity of complaints increased when provocative discussion was opened up with the viewers, it was equally clear that the number prepared to instigate a complaint in the first place was relatively small. Even in 1978, when the development of the UHF service was proceeding at a high rate and the final coverage was still uncertain, only 50,000 households complained specifically about CCI. At that time, one household contained a statistical

average of 3.2 persons, thus the total number of viewers potentially represented was about 160,000, i.e., about 0.4% of the total population. Taking account of this and the work carried out by the author ten years later when the UHF network was near complete, it seems unlikely that the proportion likely to complain about this occasional disturbance to their service would exceed 0.5%. Having regard to the fact that by then more than 99% of the population were receiving field strengths thought to be capable of providing an adequate service, this forecast seemed to support the planning standards used for the UHF development. This was a satisfying but suspect conclusion, and further analysis was carried out.

More detail concerning the impact of abnormal propagation was obtained by relating the incidence of complaints to the occurrence of "favourable" weather conditions, those in which the wind direction is likely to increase the stability of the troposphere, accompanied by rises in surface pressure. Ideally, the relationship should have been examined over a long period on a daily basis, but unfortunately the majority of the viewer reports were recorded on a weekly basis. However, taken together, the daily and weekly reports have been compared with the daily weather reports, and Figures 35 and 36 are two comprehensive examples of the results. In these figures, the number of days in each week during which abnormal propagation was likely to occur (as forecast by the stability of the troposphere) has been related to the number of complaints received from the public. As far as possible, these complaints have been positively attributed to interference caused by other broadcasting stations, generally those operating in the same channel.

Figure 35 shows the results for the VHF network, and Figure 36 deals with the UHF situation. The ordinate scales identify the weeks in the year, starting in January, and the first abscissae are the number of days in each week. The second abscissae are the number of complaints received. In both cases there is a high correlation between the number of complaints, and the forecast incidence of abnormal propagation, certainly during the summer months. In the case of the summer months it will be seen that if the favourable weather conditions persist throughout the seven days of the week, then the

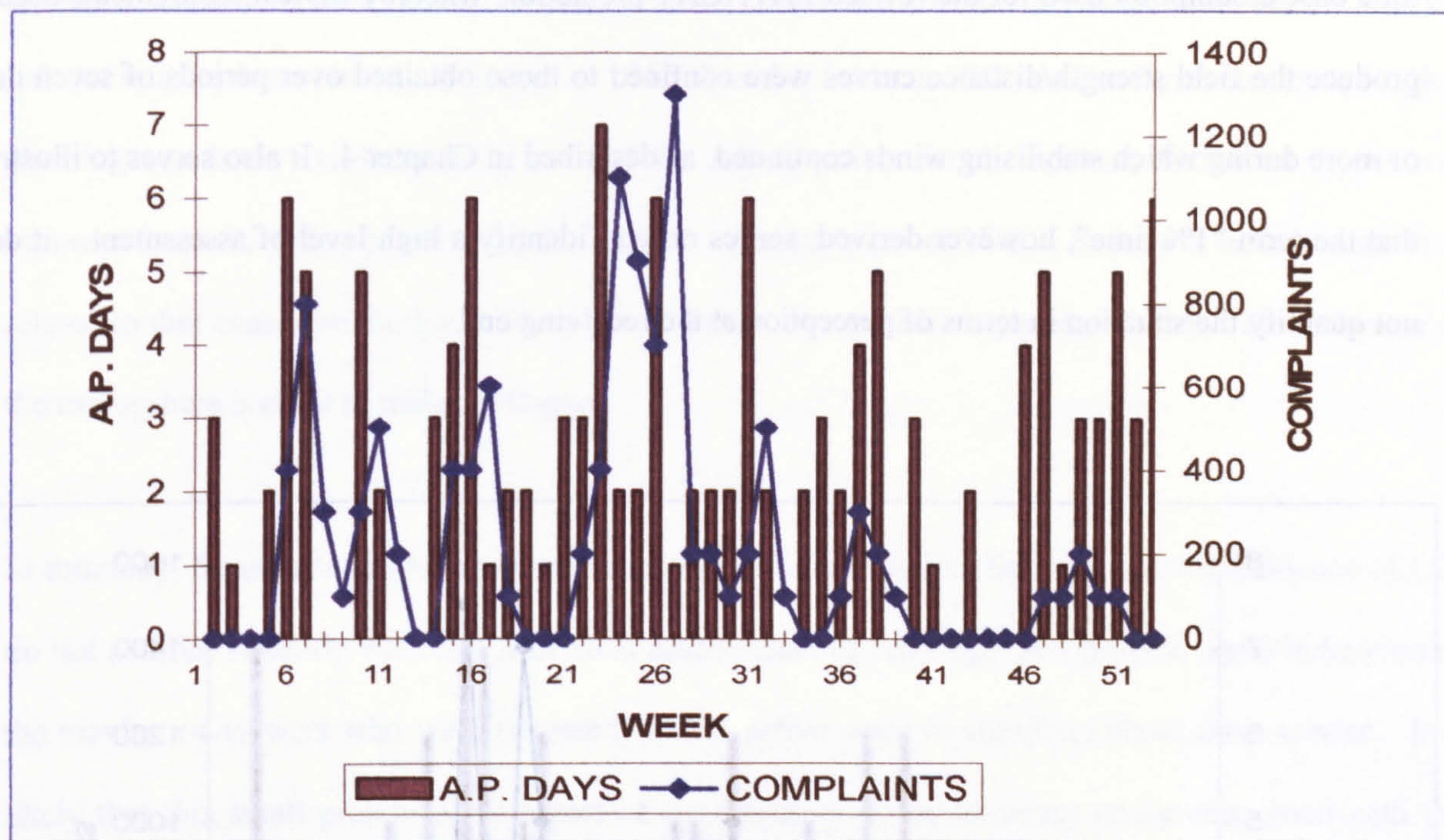


FIGURE 35
INCIDENCE OF INTERFERENCE COMPLAINTS AND
PERIODS OF TROPOSPHERIC STABILITY : VHF - 1961

The left ordinate and blue trace show the number of days in each week when abnormal propagation (A.P.) occurred. The right scale and red bars show the corresponding number of complaints from the viewers

surface pressure builds up and complaints increase. Paradoxically, the risk of this seems to diminish during the winter months, when the correlation between complaints and favourable weather conditions declines, although from audience research figures the numbers of viewers increase. Some of this anomaly can be attributed to the fact that during the period investigated, long periods of stable conditions leading to high pressures were less likely during the winter, and the levels of field strength recorded during the various experiments whilst occasionally high, seldom persisted.

Of course, results concerning the total number of complaints from individuals must be viewed with

caution, because there is no way of telling now exactly how many were repeats from the same sources.

Also, programme content is often decisive. Interference to an unpopular programme brought in few complaints, whereas an Azores High during Wimbledon week produced a very positive contribution.

However, the correlation between complaints and weather data is significant. This tends to support the

time base assumption used for the revised PATHCAT prediction, whereby LDR measurements used to produce the field strength/distance curves were confined to those obtained over periods of seven days or more during which stabilising winds continued, as described in Chapter 4. It also serves to illustrate that the term “1% time”, however derived, serves only to identify a high level of assessment – it does not quantify the situation in terms of perception at the receiving end.

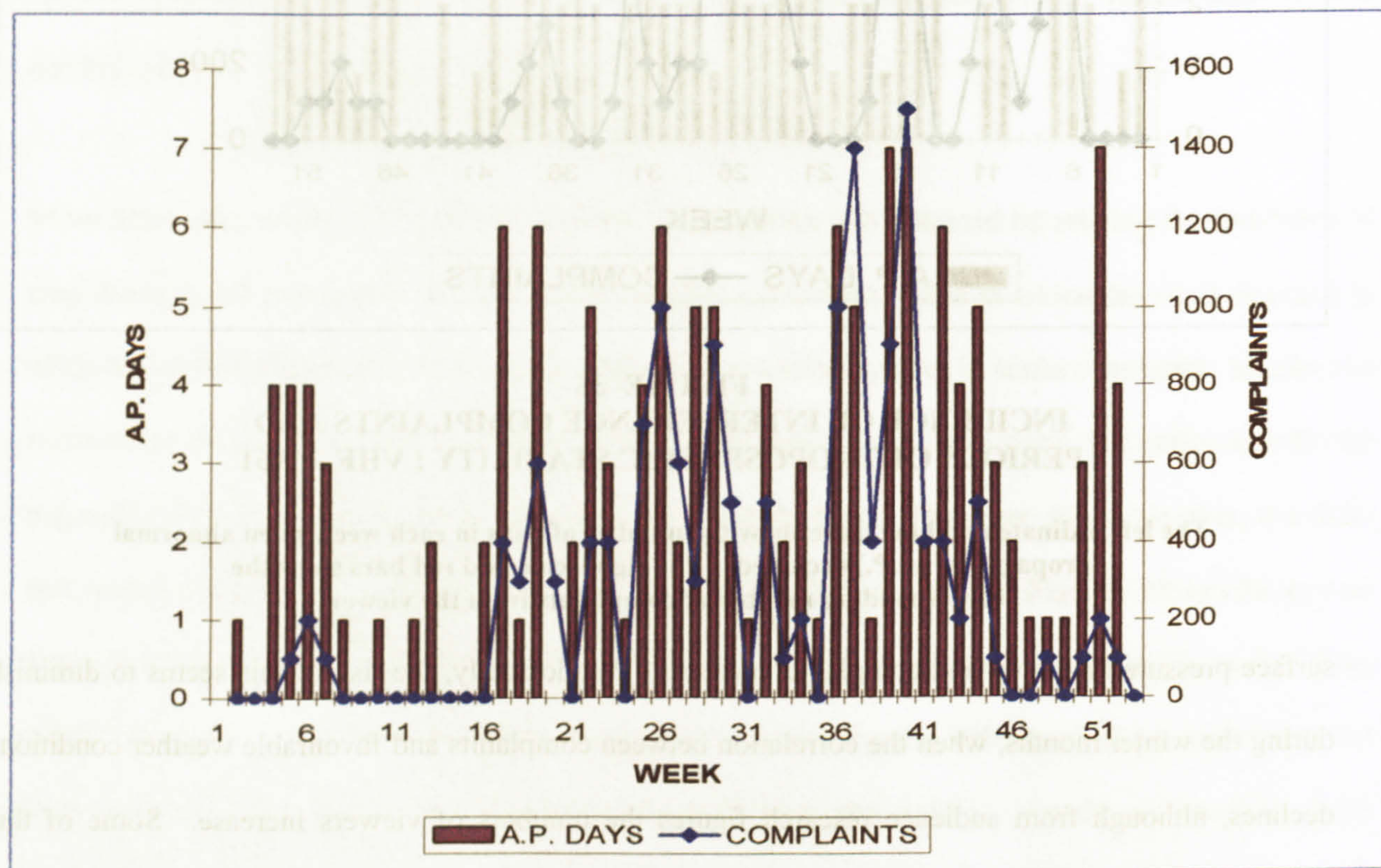


FIGURE 36
INCIDENCE OF INTERFERENCE COMPLAINTS AND
PERIODS OF TROPOSPHERIC STABILITY :UHF – 1970

The left ordinate and blue trace show the number of days in each week when abnormal propagation (A.P.) occurred. The right scale and red bars show the corresponding number of complaints from the viewers

It is disappointing that most of the analysis described above is based upon detailed information obtained in the early years, before the UHF programme was in extensive use. However, there is no reason to assume that the correlation between the incidence of abnormal propagation and complaints about CCI would diminish as the coverage increased. It is also reasonable to expect that the critical

standards of the audience would increase. All the evidence supports the earlier observations that the risks of interference were much greater at UHF than they were at VHF, and endorses the use of higher planning standards. Unfortunately, one of the selling points for the network had been that it was immune from the type of interference that had been apparent at VHF. Strictly true, this statement related to that caused to the lower channels in Band I by sporadic E propagation, but the influence of the troposphere had yet to make its impact.

In summary, these limited attempts to relate complaints from the public to the known incidence of CCI do not conflict violently with the theoretical assessments of coverage, and provide some indication of the number of viewers who were prepared to take active steps to complain about their service. It is likely that this small proportion was part of the minority of the audience really concerned with the quality of their reception, because as mentioned above the experience of the author throughout his career was that the majority accepted standards that fell below those designed by the broadcaster. Many of the receiving installations failed to make the most of the service that was available. The original equipment may have been properly installed (although at UHF the optimum domestic receiving antenna position was rarely discovered), but over the years of use, interest in the programmes took precedence over the detailed quality of the picture. The equipment was likely to receive little if any maintenance, unless there was a fairly radical fault, or a new receiver was purchased. Had the situation been different, then the network was probably over-engineered, but the margin for error was small, and in practice this "slack" was certainly absorbed at the receiving end. Importantly, the consequences of the sort of errors inherent in the official planning methods which have been discussed in this thesis have not revealed themselves in the form of widespread public complaint. It can only be observed that a better and more efficient overall result could have been achieved, but it is important now to consider this past experience and the prospects for the digital planning work.

5.5. Digital Conversion of the Terrestrial Transmitter Network

5.5.1. The Background

Only certain service planning aspects of this substantial project are discussed here, and even this is limited, because international discussion concerning the methods to be used is ongoing. The basis for most of the observations which follow has been the interim proposals which were agreed by the various working parties in the late Nineties ^(1.102, 5.18). These are being constantly updated, and further modifications will emerge.

Administratively, the introduction of digital transmission now being carried out in the UK cannot be likened to the re-engineering of the line standards and the introduction of colour which took place 30 years ago. That was entirely concentrated on the terrestrial network, and was largely within the control of the two broadcasting organizations. Each of these was responsible for the whole process of broadcast origination – producing programmes and transmitting them. In recent years the broadcasters have been effectively separated from the transmission networks, i.e., they produce programmes, and these are then directed through the terrestrial, satellite or cable channels. It is the transmission authorities who are concerned with the method of delivery, and hence the process of digital conversion. The Government maintains strategic control of the overall operation, currently through its Department of Culture, Media and Sport, although important aspects of this are soon to be delegated to a new agency – Ofcom. Imperceptibly and perhaps coincidentally, the early concept of public service broadcasting has changed quite fundamentally with this demarcation, primarily because there has been a need to meet the constant challenge of competition. However, the original proponents of such services would probably strongly argue that their fundamental objectives have not changed. Insofar as it does not apparently affect the technical processes of service planning it is not considered here, but by separating the programme makers from the distributors some coherence has been lost, noticeable, for example, when the question of resource priorities surfaces.

There is no need to discuss in depth the processes of digital transmission or the ways in which it is achieved. Fundamentally, the output from a digital studio requires about 200 Mbits/sec, which needs to be compressed to about 4 Mbits/sec. for transmission. Proposals for achieving this were made by the Motion Picture Experts Group in 1994, specifying coding techniques which used a compression factor of about 40. This could then be decompressed in the receiver to produce an output approximately equivalent in quality to the standard analogue picture. The compressed channel also included audio, conditional access and other information, which extended its width by about 50%. The modulation system adopted for terrestrial transmission was orthogonal frequency division multiplexing (OFDM), which spread the data across the spectrum whilst providing adequate protection to guard against the multipath interference expected in this operation. As a result there is very little energy at discrete points in the spectrum and this, combined with the relatively low-powers required for digital transmission, facilitates the interleaving of analogue and digital signals. Nevertheless, in the European area the problems of preparing frequency plans were, and remain, formidable. Some idea of the scale of the transition required can be obtained from the fact that within the continent more than 40,000 analogue television transmitting stations were in operation in the UHF bands by the end of the century. This represents about 130,000 channel assignments, because each station radiated a number of programmes. Most countries have achieved more than 99% population coverage on at least two or three national networks, and these services will have to be maintained whilst the new system is introduced within the same part of the frequency spectrum.

In 1996 the UK Government authorized the introduction of DTT in the existing UHF spectrum, and plans were produced whereby six multiplex services were to be transmitted from each of 81 existing television stations. It was expected that this initial network might achieve between 70% and 90% population coverage. One of these multiplexes was allocated to the BBC, and another to ITV/Channel 4. The BBC terrestrial service opened in November 1998, followed soon after by the ONdigital service, a new pay-to-view operation. However, by the end of the century the latter was in commercial difficulties. Whilst the pay-television satellite service provided by SkyDigital had reached 2.8 million

subscribers, and was busy converting all their existing analogue customers, ONdigital had achieved fewer than 675,000 viewers, and interest was waning. Two years into the new century the company went bankrupt with debts of more than £1 billion. In the meantime the satellite and cable services continued to expand, a recent estimate awarding them 32% of the population. It became obvious that the early growth for digital TV through this outlet was good, it was driven by pay TV, although an upper limit of 60% was forecast for this ^(5.19). In any case, to reach the target set for analogue switch-off of 95% set by the UK Government, a significant DTT contribution providing virtually free reception services was regarded as essential. Intriguingly, in this connection of “market share”, European planning strategies formulated by the EBU ^(1.102) placed emphasis on the provision of a terrestrial digital service to portable receivers – a very ambitious objective.

Into the new century, the latest DTT offering is Freeview – about 30 new outlets offered by a consortium consisting of the BBC, BSkyB and the transmission company Crown Castle. Intended to attract analogue viewers, it requires theoretically only a simple set-top converter, but the coverage falls well short of the old service, and the programme range is poor when compared with the number of channels offered, at a cost, by Sky. It is hoped that these “free” services will lead ultimately to greater investment by the viewers, many of whom will be tempted in time to pay extra for additional attractions, but the wide choice of outlets now on offer leaves the terrestrial service planners with a substantial burden. They are having to plan a national service, with all its concomitant demands on resources, knowing that a diminished proportion of the population will make use of it. Of course, the situation would be eased if a decision were taken to adopt a different strategy, for example, allowing the satellite and cable companies to develop their commercial multi-channel networks, but cut back the objectives of the UHF terrestrial digital system to provide a modest number of free-to-air public service broadcast outlets (no doubt there would be plenty of suggestions regarding the make-up of these). This would ease the re-engineering of the UHF terrestrial network, where currently one of the major problems is the need to protect the obsolescent analogue service.

However, in the midst of all this political and commercial tumult, detailed technical planning for the DTT service continues. A project known as "Genesis" was initiated in 1998/99, with the objective of studying the phased switchover from analogue to digital, and their report was issued in 2000 ^(5.20). Three evolutionary scenarios for further investigation were devised, only one of which achieved the 99.4% coverage figure. All three required various serious and often intricate changes to their reception arrangements by certain viewers, together with a formidable programme of transmitter modifications, which would demand extensive co-ordination, nationally and internationally. Unfortunately, the report could not deal in depth with coverage estimation, so the results quoted in this respect were conjectural. On this all-important question, international co-operation has continued within Europe, and arrangements have been made to review the propagation prediction method which for so many years has been encapsulated in ITU Recommendation 370. This will form part of a revision of the 1961 Stockholm Plan. Plans for the latter are now advanced, and three papers published by the EBU provide the background information concerning these arrangements ^(5.21, 5.22, 5.23). It is understood that the new conference will deal with the work in a number of stages, culminating in May 2004 with a first session, during which planning criteria, methods, and software will be decided. This will be followed by a second session in 2005/6 when final agreement to the frequency plan will be achieved. Between these two sessions, detailed national requirements will be formulated and international planning exercises will be carried out.

5.5.2. Observations on Future Prediction Methods

From the outset, of course, the conversion situation is complex. During their introduction, the digital transmitters have to operate alongside the analogue systems they are replacing, and the need to provide mutual protection is an onerous obligation. In the absence of any alternative strategy this condition will apply for some time, and call for interim arrangements which will have to be carefully planned and monitored. There will be demands for changes to the analogue transmissions which will allow the introduction of digital channels, similarly some of the new assignments will have to be temporarily

restrained. The process places great emphasis on the responsibilities of the planning authorities, and those of the industry that will meet the public demand. The extent to which the public is involved is critical – presumably information will be disseminated on a “need to know” basis, but this obviously presents difficulties of identification. In respect of the planning work, the ongoing activities by all those concerned are daily revealing new detail, and the situation is dynamic. Comments here are confined to basic factors which it is believed could have a serious impact on the end result, and the incidence of abnormal propagation is of particular interest, because in the past this has defined the services area limits. All the evidence suggests these conditions will be even more decisive in the operation of digital services, and prediction will become increasingly difficult.

It has already been mentioned that in the case of the analogue services, the limit of service set by the signal/noise ratio is diffuse, and only gradually becomes more annoying as the field strength of the wanted signal decreases, moving from “acceptable” to “unacceptable” over a range of about 12 to 15 dB. Somewhat different conditions apply when the “noise” is radio frequency interference, but operationally the transition is still relatively gradual. In the digital case no such smooth decay takes place, the rapid failure characteristic (the “digital cliff”) occurs within a wanted signal degradation of one decibel.

To some extent the problems of the characteristic are marginally reduced by the fact that the standard deviation of location variation for digital services is less than that recorded for analogue networks ^(2.22). However, the overall situation depends on many factors, including the minimum field strength requirement of the particular digital system, on the spectral distribution of the wanted and unwanted signals, and on the method of assessing multiple interference levels. All these features are being analysed in the planning preparations, but the problems have been heightened by two decisions which have already been taken. These are intended to deal with the situation by raising the planning standards, but the field strength levels involved are notoriously difficult to predict, and invoke yet again the problems which have been extensively described, namely the variations in time and space.

Firstly, dealing with the temporal domain, it has been decided that in order to reduce the risk of rapid failure, planning should be conducted on the basis of 1% time field strength levels, and not the 5% values used for analogue developments. Thus higher minimum field strengths must be achieved by the wanted signal in order to guard against the incidence of abnormal propagation. However, this thesis has postulated that the "official" field strength/distance curves become increasingly inaccurate as the percentage time decreases. The differences between the curves which were used for the original planning, those which have been deduced as a result of this project, and those which are now likely to be used internationally for the digital service, have been shown in Chapter 4. They demonstrate that over the range of distances critical for the incidence of CCI, the values for 1% time might be more than 10 dB above those presently predicted. This would affect many of the terrestrial viewers in southern and eastern England. To this must be added the uncertain influence of rapid fading, a feature that is taken into account by the second decision, which deals with the location aspect of field strength variation.

The incidence of rapid fading could be particularly serious, and the second decision described in the proposed planning standards recognizes this by increasing the percentage of locations required to be served at the limit of the digital service from the 50% used for analogue reception, to 95%. Under certain circumstances, a lower standard of 70% can be accepted. About 3% of the LDR recorder charts contained periods of rapid fading associated with long-term weather movements, and this detail did not materially affect the 5% time results used for analogue planning, even though individual examples lasted for several hours. Originally it was reasonably assumed these sporadic bursts would have little effect upon analogue viewers, most of whom would not notice the cyclic changes. However, the impact upon digital reception will be quite different. Of course, this feature can also be apparent for brief periods of time at all distances from the transmitter, caused by multipath from solid surfaces, e.g., aircraft flutter, but at present there is no indication of the extent of this risk.

Essentially, the last phrase summarizes the present situation. The scale of the threats to terrestrial digital viewers posed by these propagation problems is obscure, and planning has to proceed on the evidence which is agreed between the participants. Raising the planning standards on past evidence of analogue reception may not guarantee better digital coverage. The plethora of new problems means that some of the old, long-standing dilemmas have to be ignored at this stage – after all, there was no huge outcry in the past. However, if resources and investment are not to be wasted it is to be hoped that over the next few years much more will be learned during the preparation for the new frequency conference.

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6. Conclusions and Suggestions for

Further Work

The Twentieth century witnessed the introduction of broadcasting, a dynamic medium which has had a worldwide influence, and a development in which Britain took a leading role. However, although there have been very positive achievements, the broadcasting situation today is probably more confused than at any time in its history. Reasons for this have been discussed in this thesis, which has concentrated on the technical processes of planning the terrestrial transmitter networks. This approach has provided a unique insight into the overall development because it has reviewed not only the engineering and scientific problems, but has also examined the ways in which the many, often conflicting demands of all those interested in the results were accommodated.

The principal reason for the present disarray is the process of digital conversion, which particularly affects the terrestrial television networks. For nearly fifty years, these VHF/UHF transmitters have served virtually the whole of the population of the UK. Whatever technical criticism may be directed at these services, and that includes those described by the author of this thesis who was actively involved in the planning throughout those years, they satisfied a nationwide audience. That stable situation is now undergoing radical change, and this final chapter lists the author's conclusions based upon his overall experiences, and the work for this thesis.

The conclusions are separated into two groups. The first deals with the developments up to the mid-Eighties, and is broadly concerned with the evolving planning activities. The second covers the period from the Nineties, the "watershed" when the digital transition of the television network became an established objective, and implementation of the proposals started. The chapter concludes with

suggestions for further studies, where the results so far demonstrate that such research could be beneficial, having especial regard to the continued transformation that broadcasting is undergoing in the opening years of the Twenty-first century. This process of radical change is set to last for many years, and emphasizes the need for further study into features discussed in this thesis.

A) Developments to the Mid-Eighties

A1. The fundamental importance of field strength:- The planning of broadcast networks depended crucially upon the initial measurement and prediction of the field strength of radio signals, processes based on electromagnetic theory and the application of geometrical optics as they existed at the beginning of the Twentieth century. Surprisingly, in view of their importance, the early theories remained unchallenged. They were unaffected by the re-emergence of corpuscular ideas early in the century, partly because these occurred before the pioneer broadcast engineers were confronted with the real complexities of propagation science. Subsequently the concept of dualism emerged, and it was concluded that the new theories only affected frequencies well above those of interest to broadcasters. The relatively few broadcasting specialists involved in the application of theory to the development of plans accepted that their pragmatic prediction techniques were compromises, although this was attributed to shortage of evidence, rather than flawed theories.

A2. Inadequate data:- Inability to identify precisely the many factors which quantify all the direct and reflected components of the signal which arrive at the receiving antenna was seen as the main problem. Even attempts to predict the spatial variation of a signal over a very short path were subject to errors, and these increased with path length, as the number of alternative rays between terminating antennas multiplied. This obstructed attempts to define the variation of field strength in the separate domains of time and space, a particular difficulty in broadcast planning, which requires point-to-area as distinct from point-to-point prediction. Substantial reliance was placed on simple statistics to estimate the extent of the many "random" influences which affect field strength distributions, and the thesis has

described the impact upon the all-important planning parameters. Nevertheless, the propagation theories remained inviolate, so priority was given to acquiring more data to define each propagation path. This led to increasingly ambitious databases, and prediction complexity – both dramatically facilitated by the introduction of computers. Despite this, the improvements in precision were modest, although this conclusion in turn raises the question of confirmation.

A3. The precision of a prediction model, and the impact upon planning:- The usual means of checking this, by comparison with field strength measurements, almost invariably produced optimistic conclusions, because the results used to develop a method were then used to test it. Effectively the scope of the technique was established by local propagation conditions, and its application in other environments frequently exposed problems. This largely explains the enduring worldwide support for the simple prediction described in CCIR Recommendation 370, which was used for international negotiation for more than 50 years. It was based upon a relatively small number of measurements contributed by a few countries in the early stages of broadcasting development, but later attempts to introduce national ideas to improve the international technique often failed because tests against measurements in other countries did not support the proposals. There were also other less-informed objections from countries wishing to retain the status quo. Inability to agree a better international approach remained an enduring restraint, and the spectrum was inefficiently exploited. Another less obvious but important legacy was that the geographical layout of the hundreds of high-power stations planned using the early methods formed the framework of the dense networks of thousands of transmitters that were eventually required. Administrations were extremely reluctant to abandon the large, expensive installations as services developed, even though improved planning methods often suggested better coverage might have been achieved using alternative transmitting sites.

A4. The Real Value of Recommendation 370:- Several criticisms have been levelled against this prediction, but throughout it was vital for international negotiations. It could not provide the detailed design information needed to specify the precise operating conditions of each national transmitter, and

for many years national planning in some countries used a mixture of the recommended prediction to calculate unwanted interference levels from foreign stations, and their own more accurate methods to determine the strength of the wanted service – a questionable procedure because of the mix of measurement standards upon which the methods were based. However, whilst absolute precision proved elusive, the Recommendation provided clues regarding the tendency of planning proposals, i.e., successive predictions carried out for varied transmitting conditions could reveal the trend - show whether or not situations were likely to be improved. Its simple, undemanding format was also readily converted for computer application, and it was used for international investigations into several large scale projects.

A5. The gap between planned and actual coverage assessments:- Throughout, as field strength was the essential quantitative result demanded by the planning engineer, the links between it and the user's assessment of the quality of reception had to be established by subjective tests. The early studies were relatively simple, and subsequent experience exposed the importance of factors such as interest in the programme, the duration and intensity of any interference, and the efficiency of the receiving installation. In the development stages these factors remained relatively neglected, and unfortunately a potentially useful feedback path from users to planners was never developed. There was a persistent gap between the planning engineer's concept of the theoretical coverage, which provided the evidence for his work, and the results perceived by the users. This was never filled.

A6. Planning co-ordination:- Difficulties in the preparation of plans for all types of radio services could often be traced to differences of opinion concerning the overall strategy for the use of the spectrum. During the development period the demand for frequencies was dynamic and indeed continued to accelerate. The spectrum was the vital resource which was to dictate the scope of all new services. Completely novel radio systems which could not observe administrative boundaries were being developed around the world. Various transmission techniques were being introduced, and new, very substantial industries were emerging. With so many different disciplines, interests, timescales and

countries involved, international agreement on the allocation of the finite radio spectrum, and on the planning parameters to be used in this process, was arduous. Naturally, there were similar problems at the national level, where the Government had the responsibility of awarding allocations to the many operators, and ensuring the agreed planning standards were observed. The importance of co-ordination became increasingly apparent. In the case of broadcasting, the transmission systems and the coverage objectives were usually proposed by their organizations. Technical planning was carried out by their engineers, and involved negotiations with many other organizations. International liaison on new systems was often conducted through the appropriate EBU working party. Some of these activities were duplicated by Government departments or agencies, working at the international level through specialist groups within the ITU/CCIR, with particular reference to planning standards. As far as the broadcasting engineers were concerned, several had to participate in both EBU and ITU/CCIR activities, to ensure their proposals were not only practicable, but were also likely to be acceptable to those ultimately responsible for international agreement. Furthermore, in the case of coverage plans, at an early stage they had to negotiate with land owners and planning authorities to ensure sites were available for transmitters. Preliminary design work had to be completed on each installation, for example to ensure that particularly demanding transmitting antenna proposals were achievable. Consideration had also to be given to the need to share a site with another broadcaster or communication authority. Subsequent decisions regarding long-term strategic objectives occasionally disrupted the tactical plans, and new proposals had to be prepared. The whole process was immensely complicated, and there was substantial duplication of effort. Much higher levels of efficiency in the deployment of resources were achieved when responsibilities for *technical* planning were assigned to one authority, ensuring that equal priority was given to studying the coverage aspirations of all the organizations concerned, and in this context the recent introduction of Ofcom might be propitious.

A7. Inadequate research:- The previous conclusions have frequently identified the need for more information, and many examples have been described in this thesis where the demands overwhelmed the research and planning resources. Typically the BBC, which provided much of the basic

propagation evidence throughout the VHF/UHF developments, undertook a great deal of research, but promising projects had often to be condensed or abandoned because of the pressure to deal with other schemes. The situation deteriorated as the number of broadcasters increased, competition intensified and costs became a dominant factor. The altruistic approach very evident in the early days when information was readily shared, gave way to commercial pressures, and the opportunities to co-ordinate expensive research projects were reduced.

A8. The relationship between government and broadcasters:- Continuing the theme of co-ordination during the development phase, fundamental problems existed from the outset between the two major participants in the UK, the BBC and the government. These also led to some occasional internal strife between the BBC's executives – the Board of Management - and its Board of Governors. It is difficult to see how these could have been overcome in the early years, given the enduring arrangements for broadcasting that were established in the Twenties. A picture emerges of enthusiasts led by a dedicated and single-minded management, desperate to introduce a torrent of ideas and philosophies, but confronted by suspicious politicians with their own beliefs about the ways in which the medium should develop. Although publicly the broadcasters had editorial freedom, the government had effective control over the finances and the disposal of the radio spectrum. A perpetual confusion became the meaning of "public service broadcasting", a concept that acquired some sort of idealised status – demanding priority. The original, formulated by John Reith, established a pattern of ethical standards which he felt were appropriate, but which has long since been modified by social changes. Competition in the form of commercial radio and television was probably good for the users, and indeed was regarded by many as a blast of fresh air, although this point could be argued. In terms of the original ideals of public service broadcasting it might seem that occasionally the objective was the lowest common denominator in terms of taste. Of course, more channels meant more choice, but it led to in-fighting between the programme makers in their struggles for ratings supremacy. Although superficially all these machinations had little effect on the technical activities, they influenced working relationships, and there were several occasions when "political" solutions required changes to more

efficient plans.

A9. Public response in the past:- The significance of each successive technical stage of broadcasting can be judged by a surge in the public demand for the services. "Wireless" began as a hobby; it was a new, inexpensive and fascinating form of entertainment that expanded at a modest rate, but the "small window on the world" which was introduced a couple of decades later was a phenomenon. Given the catharsis which affected virtually every aspect of public life after the '39/45 war, the only limit on the volume of the demand for television by the people was the speed at which the broadcasters could build transmitters. The real growth started in the mid-Fifties with the introduction of more programmes, boosted a decade later by the revelation of colour. Near-national coverage was achieved by the Seventies, and the next radical development to higher definition television, made possible by the move to UHF, was achieved without difficulty. These individual transitions were massive, distinctive improvements in the terrestrial services, and interest in the medium was substantially stimulated on each occasion - commercially they were very successful. However, during the Eighties, as the "consumer society" developed, improvements in broadcasting technology concentrated largely upon better receivers and reception quality, relatively minor but still profitable factors. Even the attractions of satellite transmission did not have the immediate impact of the early developments, receiving only slow and almost dubious acceptance. This accounts for the paradox which the author noted in the development of the new field strength prediction described in this thesis. Encouraging results were obtained when it was used to compare the 1970's coverage achieved by the UK terrestrial television services. The number of complaints was limited, and this suggested that the early planning methods must have been adequate, but it became clear that users in those days were much more concerned with the unfolding phenomena of broadcasting than they were with the precise technical quality of their reception. By the Eighties, audiences were becoming much more sophisticated and analytical. There was increasing competition from alternative forms of electronic entertainment, and the studio quality obtained from recorded material highlighted the deficiencies of off-air reception. Some exciting new initiative was required from the broadcasters.

B) The watershed of the Nineties

B1. The Impact of Digital Transmission:- The future of broadcasting, certainly that of the terrestrial service within the UK, was profoundly affected by the decisions taken in the Nineties to move to digital transmission. Many advantages, some of them not immediately very obvious to the user, were claimed. The problems of transition were said to be difficult, but not insurmountable. However, the obstacles were underestimated, and the situation was made worse because it was a period of official indecision, during which clear directives concerning the future were conspicuous by their absence. It seemed that faced with a flood of evidence, much of it conflicting, the Government decided to monitor the situation and observe market developments. Whilst acknowledging there were reasons why a wait-and-see policy was adopted, it is particularly unfortunate that this has persisted through the period when the digital re-engineering process is taking place. The original guidance to the broadcasters investing in these complex projects was that the government would close down the analogue networks when digital services "are available to 95% of the population". Disregarding the fate of the three million or so viewers excluded by this standard, and the real costs of fully modifying every domestic receiving installation (at the time of writing still not reliably estimated), it must also be implied that there is no great concern about the source of the replacement services. It does not matter to the Government whether or not this objective is achieved by terrestrial, satellite or cable. Thus it leaves those concerned with the planning of the DTT network with at least one serious uncertainty - do they persist with the early objective of achieving national coverage within the same spectrum, a costly ideal which is becoming increasingly challenging if the *full* potential of digital transmission is to be realized (including HDTV), or aim for something more modest? No doubt, a national broadcaster will want national coverage (he may even wish to achieve this on all possible transmission media – triplication!). In this process, the broadcaster will also have to implement a rigorous conversion programme to protect the obsolete analogue services. Yet with the present arrangements the population using the DTT service will diminish, as some viewers turn to the satellite or cable services. The European

situation is also fluid. The conditions at the interface between the UK and continental networks have been broadly agreed, the technical parameters needed to implement digital operations exist, and international planning is forging ahead. But the devil is in the detail, and much depends upon the outcome of the imminent frequency planning conference, in itself an enormous project.

B2. Doubts concerning the planning methods:- The work described in this thesis emphasizes the fundamental nature of field strength prediction, a detail having a significance only fully appreciated by the few planners close to the problems. The results discussed in this thesis suggest that the geographic situation of the UK renders it particularly vulnerable to transmissions from the European mainland (and vice-versa), because oversea sections of propagation paths are likely to increase both the incidence and the duration of stable upper air conditions supporting long-distance propagation. Digital terrestrial reception may well be more sensitive to interference at these times than analogue, having regard to the instant failure characteristic of the system. This recent work also postulates that in particular, field strength levels may be much higher during periods of abnormal propagation than the prediction techniques presently used for international planning forecast. If these prognostications are valid, then they place a question mark over certain details of the new plan

B3. The impact upon the public:- The impact upon the public of the digital decision is serious, and aggravated by the lack of reliable, non-commercial, user-friendly information concerning the new services. Indeed, the volume of reception complaints began to increase in the Eighties, at the very time when official machinery to deal with them was under sentence. Now, already bemused by the flood of electronic entertainment/information equipment that fills the market, consistent advice on what to buy is hard to find, especially when the long-term situation is taken into account, i.e., the reliability and cost of the service. There has already been the unfortunate example of ON-digital, and certainly this is an area which has deteriorated in recent years. At one time it was possible to obtain advice from dealers on what were relatively simple reception requirements, and any interference problems were dealt with by reasonably efficient information services run by the GPO and the broadcasters. Now that

the market options have increased, the public receives much less attention once a sale has been achieved. The equipment at the receiving end can be worryingly complex, and it is very doubtful if more than a small percentage of the users know how to identify their requirements, to specify the equipment they need, or to operate it satisfactorily. Meanwhile technology accelerates, introducing a flood of new developments, which often worry those who have already invested in what may well be obsolescent equipment, or hardens the resolve of those coming under the heading of "wait and see". Never in the history of broadcasting has so much money been lavished by so many, so whatever else this must be seen as a commercial success. However, for the public, broadcast reception has simply become another public utility, which must offer the popular feature - choice. The situation is technology-driven, and in common with the supply of other resources, increasingly in the future it will be received in different ways. Inevitably the revolution in domestic communications will continue.

C) Suggestions for Further Work

C1. Propagation research:- Summarised under A1) and A2) above, there were many occasions in the past when measurements could not be reconciled with prediction theories. Notable were the discrepancies on the long, trans-horizon paths, where under abnormal propagation conditions, free-space values were often well-exceeded at the higher frequencies, whereas these levels were seldom reached on the shorter line-of-sight paths. There were also several other anomalies, including the measurements repeated over a period of decades showing increases in field strength levels - are there some indefinable changes in the transmission medium, perhaps a result of a vast increase in the amount of electromagnetic energy radiated from terrestrial transmitters since the beginning of the century? There was some progress during this project, for example, the overlap between time and location domains was exposed in more detail, together with the influence of terrain upon their distributions. However, much information remains buried in the measurements which have been made by many researchers over the last 50 years. With meteorological/hydrological data and the highly detailed terrain information now available, a comprehensive research programme into VHF/UHF propagation

would certainly reveal new evidence. The results would be too late for the imminent plans for the new broadcast networks, but surely determined attempts should be made to learn more about radio propagation and reveal the true costs of every radiated decibel of electromagnetic energy.

C2. Information regarding the take-up of the services:- This serious problem was mentioned in A5) above. The situation today is even worse today than it was 20 years ago, largely due to the digital revolution. Of course, there is an urgent need for more information to be given to the users, and this aspect is discussed later, but this point focuses on the supply of data to the planners. This would also interest many others – administrators, advertisers, and so on – knowledge of the results of the deployment of resources is valuable. Surveys are conducted by various commercial companies at present, but their main interest is in programme popularity. A research project could be devised to investigate the possibilities of providing feedback for the planners. For example, one simple possibility - if the universal licence fee is to continue, then it might record the type of installation, i.e., terrestrial, satellite or cable. Alternatively, various electronic techniques can identify the transmitter source at each receiver, or retailers could be asked to supply information concerning domestic installations. No doubt some of these ideas would be socially unacceptable, but the need justifies exploration.

C3. Planning co-ordination:- Associated problems were outlined in A6) and A7) above, but the opportunities or demand for further work in this area are unknown, because it depends upon the mandate of the new Government agency - Ofcom. Certainly the most serious underlying difficulty which continuously surfaced throughout the broadcasting development concerned the overall administration and organization of spectrum planning. During the early days, the original chain of research and development work functioned reasonably efficiently through a complex, partly informal, network, but problems in the final administrative stages could cause serious delays. There was also substantial duplication, certainly at the national level, during the planning stages. The virtues of a single planning authority were extolled in this thesis, and the potential value of Ofcom was mentioned.

Their present responsibilities embrace television, radio, telecommunications and wireless communications services, and it was hoped the introduction of what is, effectively, a single regulatory authority, would facilitate co-ordination and agreement at the national level throughout. It could monitor national resources, including research, identify deficiencies, and assemble ideas concerning long-term strategy. Given the necessary expertise, it could also oversee the final international activities. These would be unique and valuable contributions, and it could be regarded as the source of reliable information on all matters concerning the use of the radio spectrum. To achieve such results it is important to appreciate that their technical authority should equal their administrative qualities. But with so many disparate interests using the spectrum, thousands of installations in operation, several formal and informal organizations already engaged in negotiation, the prospect of national co-ordination by a single organization may be unrealistic. Furthermore, there may be a fundamental philosophical problem. As mentioned above, in the early days the situation worsened as competition expanded and research became a restricted subject. Significantly, the mandate of Ofcom as outlined in the Communications Act of 2003 encourages them to promote competition in relevant markets. Already clear in their Spectrum Framework Review published in November 2004, a recent example of the latter philosophy is a proposal^{*} to end the “command and control” approach previously adopted for the allocation of the radio spectrum, on the grounds that this is a manifestation of unnecessary bureaucracy. Citing operations in the USA, the preferred alternative is to apply “market mechanisms, controlling the use of the spectrum by charging for its use – in the hope that this would restrict demand. However, wisely in their argument it is observed that these proposals would need international agreement. This is certainly true, because our immediate European neighbours have their own very national objectives, and they are on our doorstep. In this context, it is observed from past experience of broadcasting services that it is necessary to be cautious of experiences in the USA, so frequently quoted in the past, because their allocation problems and coverage solutions are quite different from those in Europe. As mentioned at the beginning of this item, specific proposals for further study cannot be made at this stage, but it will be important to monitor the national machinery for allocating

^{*} “Up the Revolution” William Webb IEE Review pp 45 -47 May 2005

the spectrum which is now being organized. Properly conceived, this could realize many benefits

C4. The future of the BBC:- Conclusion B1) discussed the various dilemmas facing broadcasters, especially those concerned with the DTT network. Coincidentally at the time of writing there is much discussion concerning the future shape of the BBC*, and many alternatives are presumably being considered by the Government before they issue their White Paper on the subject, scheduled for the end of 2005. It is a feature which could influence spectrum use and the whole future shape of broadcasting, so it is hoped the White Paper will provide the comprehensive analysis that the situation demands. If it does, it will demand substantial study. If it does not, it will provoke many questions.

C5. Reliability of the Planning Methods:- An aspect mentioned in B2) above, information should be obtained as soon as possible regarding the propagation forecasts made in this thesis, which contrast with those achieved using international predictions. It is suggested that early monitoring of the reception conditions of the developing terrestrial digital service could reveal valuable information, and a survey of areas where predictions show reception conditions might be affected should be arranged. In particular, the results obtained from past measurements that strongly indicated abnormal propagation levels were not materially attenuated by local terrain should be confirmed or denied. However, even given a new prediction method, the eventual interference situation can only be fully assessed when more information is available concerning the plans for networks in adjacent countries.

C6. The future of the Terrestrial Network:- The digital decision is irreversible, but beyond concluding that all viewers will eventually abandon analogue reception, future public response is uncertain. So many choices have to be made available for them by the planners that there is little room for cost savings at the transmitting end - programme material has to be duplicated/triplicated on terrestrial, satellite and cable outlets, because it must be assumed, in the case of a national service, that everyone must be served. But the attractions of the terrestrial alternative may be diminishing, having

* BBC Charter Review: Green Paper Consultation DCMS web site <feedback@culture.gsi.gov.uk>

particular regard to its demands on the radio spectrum, the visual impact of hundreds of masts upon the environment, and the attractions of the alternative means of delivery, already mentioned above. Nevertheless, substantial investment is being made by broadcasters and a significant proportion of the public in DTT. If the outlet is to continue, and not just as blots on the landscape, then surely early action must be taken to identify the real contribution it could make. The potential is there. For example, the transmitter network could be rationalized to provide both VHF radio and UHF television, reducing the present number of sites. Ignoring television for the moment and considering the LF/MF transmitters, aren't the present arrangements for radio broadcasting somewhat archaic? The possibility of producing an integrated plan using selected sites for interactive services, including mobile telephone systems, should also be examined, again this might substantially reduce the number of installations required. Without some such ambitious programme, the question must be asked -- are vast resources being expended to achieve the unnecessary? Should a programme of total closure of the terrestrial network even be considered, because the progress of technology suggests satellite and cable distribution will be much more efficient means of achieving the ideas that are now developing? Whatever the answer, it should come sooner rather than later.

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